IN THE EASTERN DISTRICT OF TEXAS
BEAUMONT DIVISION

TDE PETROLEUM DATA SOLUTIONS, INC. PLAINTIFF v.	)	Civil Action No.:
MOBLIZE, INC. DEFENDANT.	)	JURY TRIAL DEMANDED FED.R.CIV.P.38

DECLARATION OF DR. MICHAEL NIKOLAOU IN SUPPORT OF PLAINTIFF TDE'S MOTION FOR PRELIMINARY INJUNCTION

My name is Dr. Michael Nikolaou, and I have personal knowledge of the facts set forth below and I state:

1. I am an Engineering Professor at the University of Houston in Houston, Texas. I have attached a true and correct copy of my C.V. to my Declaration.
2. I am serving as an expert for Plaintiff TDE Petroleum Data Solutions, Inc. concerning Defendant Moblize, Inc.'s infringement of U.S. Patent No. 6,892,812. I may refer to U.S. Patent No. 6,892,812 as the '812 patent. A true and correct copy of the '812 patent is attached to my Declaration.
3. In preparation for giving my opinion concerning Moblize's infringement, I have read the '812 patent and also reviewed Defendant Moblize's website at www.moblize.com. As such, I have only relied on information about Moblize that is publicly available.
4. As demonstrated in the claim charts below, it is my opinion that Defendant Moblize infringes at least claims 1 and 31 of the '812 patent.

5. This is not to say that Moblize does not infringe claims 2-30 and 32-115. At the present time, my Declaration does not contain an opinion concerning infringement of claims 2-30 and 32-115 of the ‘812 patent.
6. My claim charts for claims 1 and 31 of U.S. Patent No. 6,892,812 are reproduced below:

<u>CLAIM 1</u>

Claim 1 of ‘812 patent	Literally practiced by Moblize’s system? (Times indicate minute and seconds of Moblize website video)	Equivalent practiced by Mobilize system?
An automated method for determining the state of a well operation, comprising:	YES. Video - 2:59 – *“The NPT[1] analysis tab off of the main menu instantly shows you a breakdown of all daily activities and defines ILT[2] and NPT automatically based on our smart rig states.”*	Yes – if literally present; also present as equivalent.
storing a plurality of states for a well operation;	YES. Video: 0:35 – *“The wells can be searched … instantly.”* Video - 0:48 – “*allows you to break down and compares all connection times by rigs, or by pads in a region. … Just create groups and add groups as needed.* Video - 2:59 – “*The NPT analysis tab off of the main menu instantly shows you a breakdown of all daily activities and defines your ILT and NPT automatically based on our smart rig states.*” These activities require that the “states of the well operation” are stored.	Yes – if literally present; also present as equivalent.

[1] NPT is “Non-Productive Time.”
[2] ILT is “Invisible Lost Time.”

	Examples: Figure 1. Screenshot from http://moblize.com/what-we-do/. and Figure 2. Screenshot from http://moblize.com/what-we-do/.	
receiving mechanical and hydraulic data reported for the well operation from a plurality of systems; and	YES. Video – 1:51 – *"By selecting the torque and drag tab from the menu, you will see a plot showing pick-up or slack-off weights, rotating weight, and rotating torque, calculated automatically from real-time EDR[3] data."* (mechanical data) Schematic at http://moblize.com/what-we-do/ (Figure 3. Screenshot from http://moblize.com/what-we-do/.) states that: "*Moblize's Aggregators can also be deployed in the field if required to wirelessly connect to … Coriolis meters, flow meter …*" (hydraulic data) Thus, these are mechanical and hydraulic data reported for a drilling operation.	Yes – if literally present; also present as equivalent.
determining that at least some of the data is valid by comparing that at least some of the data to at least one limit, the at least one limit indicative of a threshold at which the at least some of the data do not accurately represent the mechanical or hydraulic condition purportedly represented by the	YES. Video: 2:13 – "*You can even quality-control the procedures in place for the torque and drag real-time calibration …*" At http://moblize.com/what-we-do/ (Figure 4. Screenshot from http://moblize.com/what-we-do/.) "*Moblize's Early Warning Command Centers (EWC's) proactively monitor all service provider data around the clock to ensure quality control and data accuracy. … to reduce*	Yes – if literally present; also present as equivalent.

[3] An "EDR" is an "Electronic Drilling Recorder."

at least some of the data; and	*incidences of missing or incomplete data and false calibrations that can lead to costly down time.*" Calibration ensures that measurements are not out of range (above an upper bound or below a lower bound) Moblize's homepage (Figure 5. Screenshot from www.moblize.com.) also states that: *"Moblize provides you with the highest standard in big data quality … ."* Data validity to the "highest standard" must include comparison to a limit to ensure that at least some of the data is valid.	
when the at least some of the data are valid, based on the mechanical and hydraulic data, automatically selecting one of the states as the state of the well operation.	YES. Video: 1:25 – "*You can analyze single-well connection times and break down from slip-to-bottom, slip-slip, bottom-to-slip.*" Video - 2:59 - "*The NPT analysis tab off of the main menu instantly shows you a breakdown of all daily activities and defines your ILT and NPT automatically based on our smart rig states.*"	Yes – if literally present; also present as equivalent.

<u>CLAIM 31</u>

Claim 31 of '812 patent	Literally practiced by Moblize's system? (Times indicate minute and seconds of Moblize website video)	Equivalent practiced by Mobilize system?
31. An automated system for determining the state of a well operation comprising:	YES. Video - 2:59 – *"The NPT analysis tab off of the main menu instantly shows you a breakdown*	Yes – if literally present; also present as equivalent

	of all daily activities and defines ILT and NPT automatically based on our smart rig states."	
means for storing a plurality of states for a well operation;	YES. Video – 0:17 - The video on the home page of Moblize's website shows a tablet and the video mentions that you can *"simply log from anywhere .. via smart devices."* Video - 0:35 – "*The wells can be searched instantly.*" Video - 0:48 – *"… allows you to break down and compare all connection times by rigs, or by pads in a region … Just create groups and add groups as needed."* Moblize's activities require that the requisite information is stored.	Yes – if literally present; also present as equivalent
means for determining that at least some received mechanical and hydraulic data is valid by comparing the at least some of the data to at least one limit, the at least one limit indicative of a threshold at which the at least some of the data does not accurately represent the mechanical or hydraulic condition purportedly represented by the at least some of the data; and	YES. Video - 2:13 – *"You can even quality control the procedures in place for the torque and drag real-time calibration."* At http://moblize.com/what-we-do/ *"Moblize's Early Warning Command Centers (EWC's) proactively monitor all service*	Yes – if literally present; also present as equivalent

	provider data around the clock to ensure quality control and data accuracy. … to reduce incidences of missing or incomplete data and false calibrations that can lead to costly down time." Calibration ensures that measurements are not out of range (above an upper bound or below a lower bound) Moblize's homepage also states that: *"Moblize provides you with the highest standard in big data quality … ."* Data validity to the "highest standard" must include comparison to a limit to ensure that at least some of the data is valid.	
means for automatically selecting one of the states based on mechanical and hydraulic data as the state of the well operation when the at least some of the mechanical and hydraulic data are valid.	YES. Video - 1:25 – *"You can analyze single-well connection times and break down from slip-to-bottom, slip-slip, bottom-to-slip."* Video - 2:59 – *"The NPT analysis tab off of the main menu instantly shows you a breakdown of all daily activities and defines your ILT and NPT automatically based on our smart rig states."*	Yes – if literally present; also present as equivalent

I give this Declaration upon my own personal knowledge and I declare under penalty of perjury, pursuant to 28 U.S.C. §1746, that the foregoing is true and correct.

Respectfully submitted,

Dr. Michael Nikolaou

Date: 4/30/15

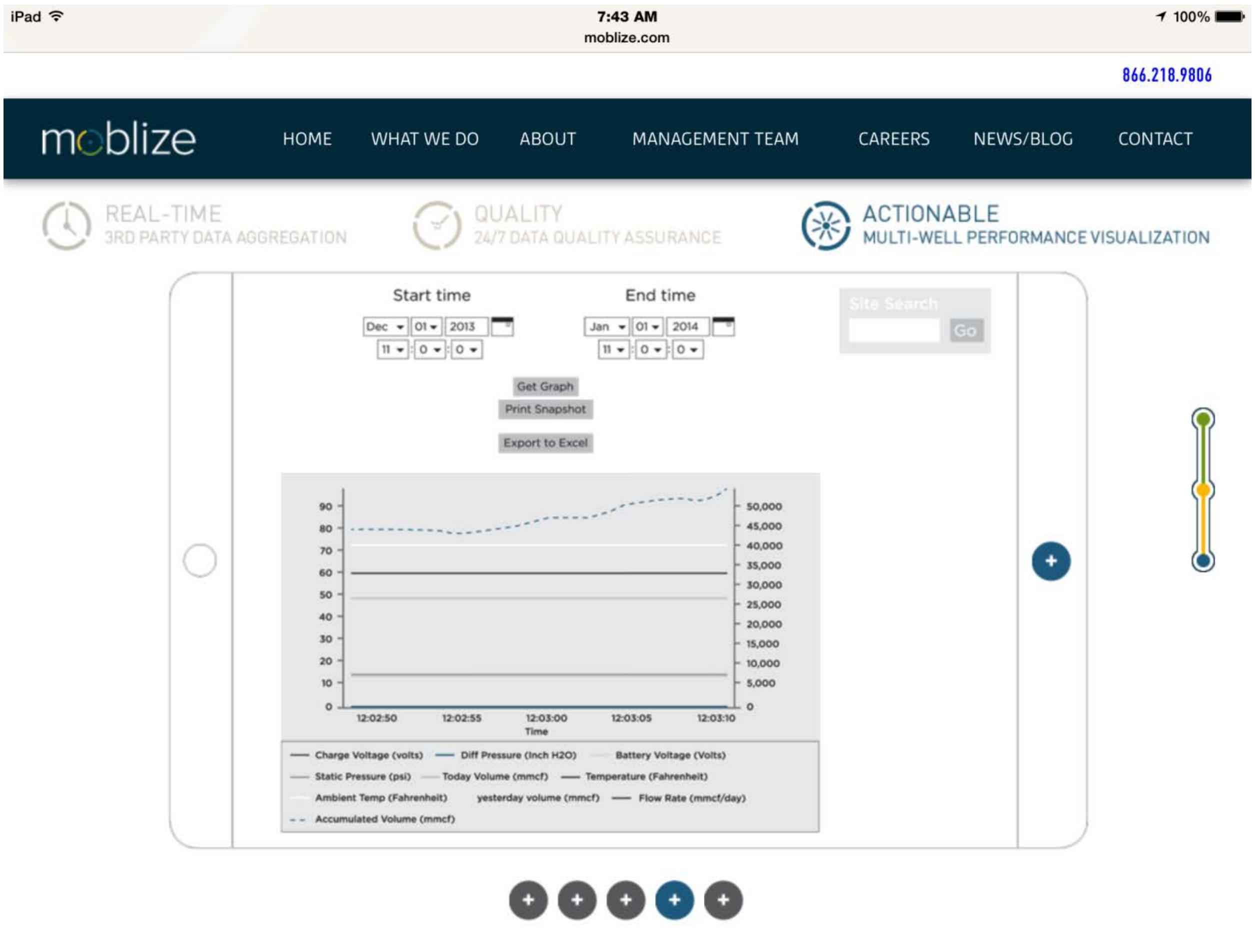

Figure 1. Screenshot from http://moblize.com/what-we-do/.

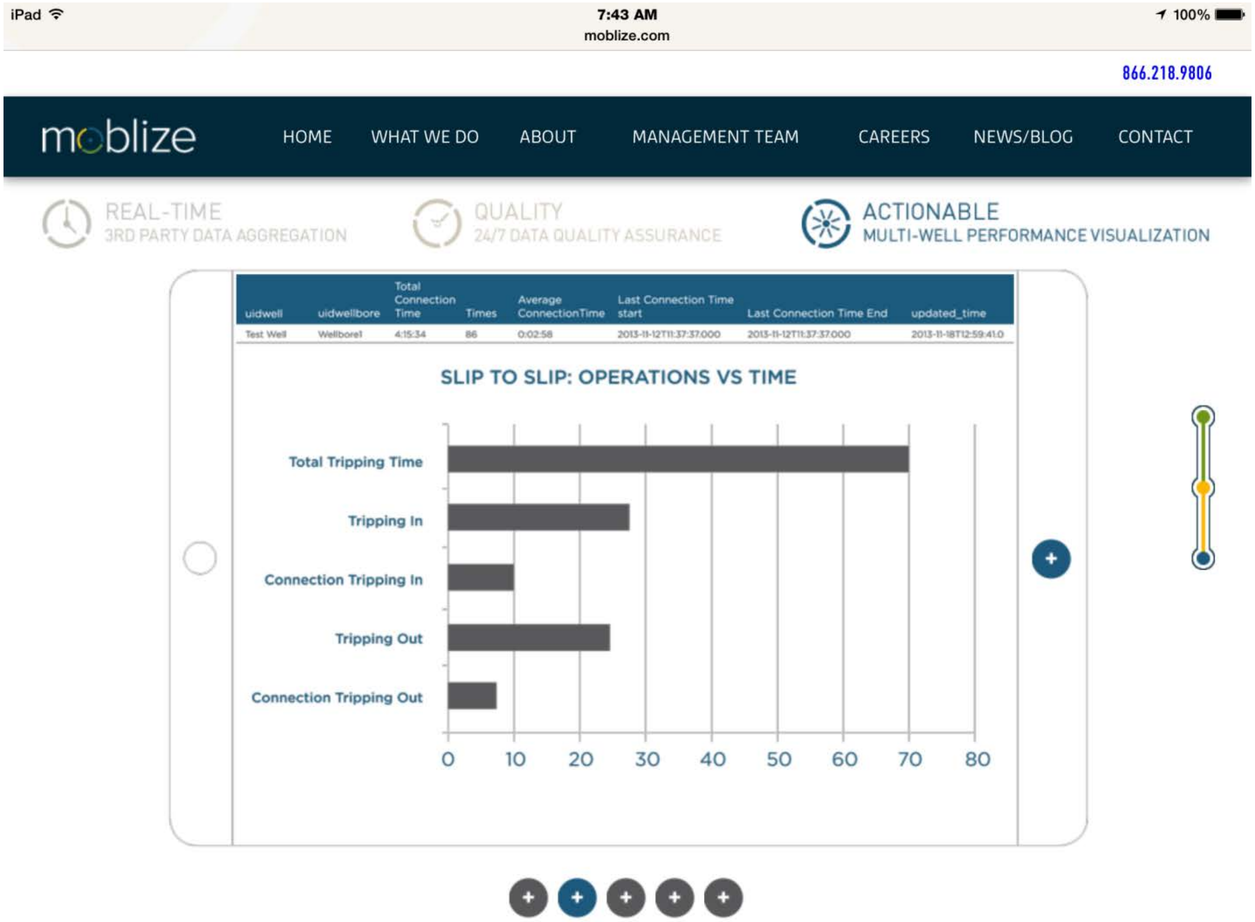

Figure 2. Screenshot from [http://moblize.com/what-we-do/.](http://moblize.com/what-we-do/)

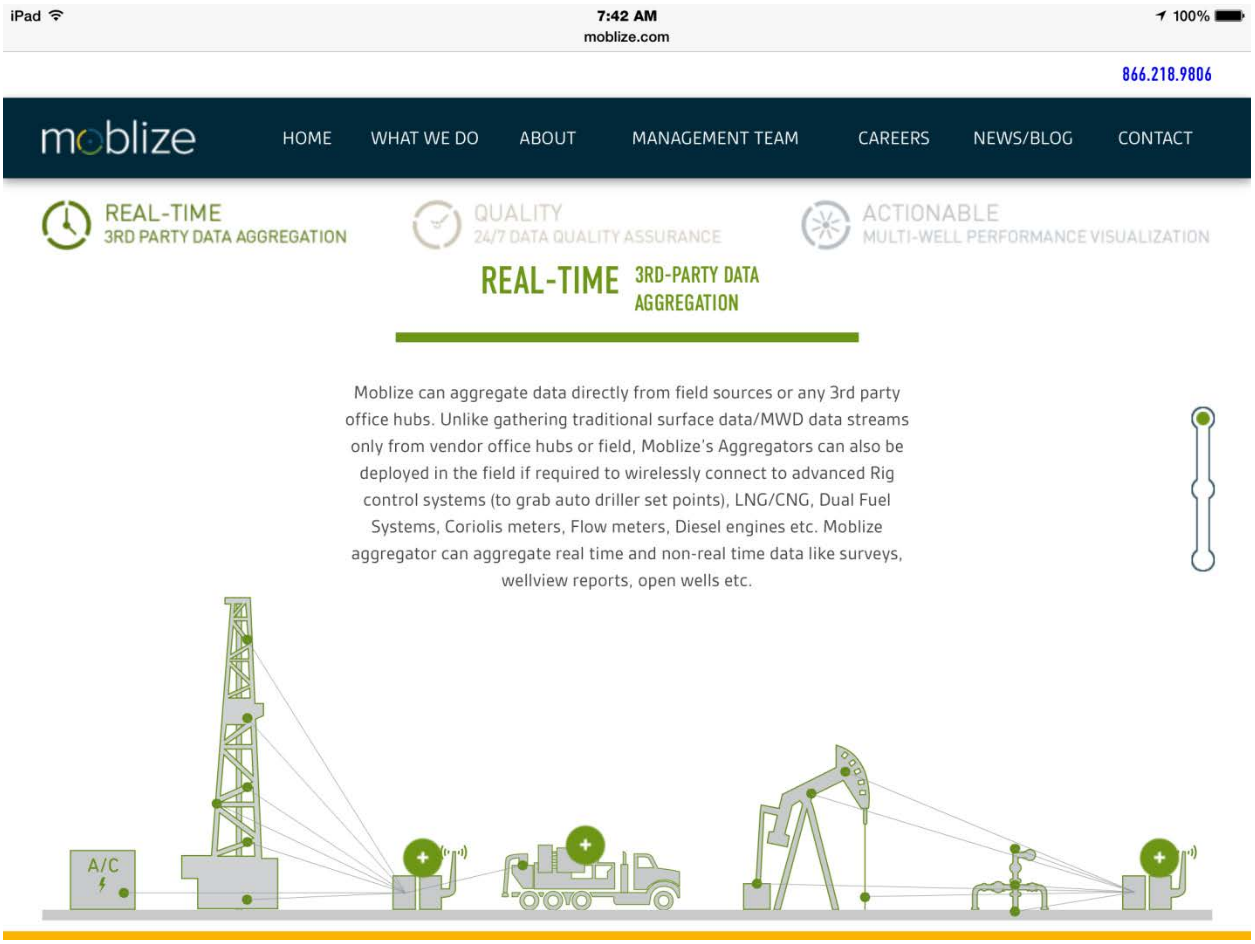

Figure 3. Screenshot from [http://moblize.com/what-we-do/.](http://moblize.com/what-we-do/)

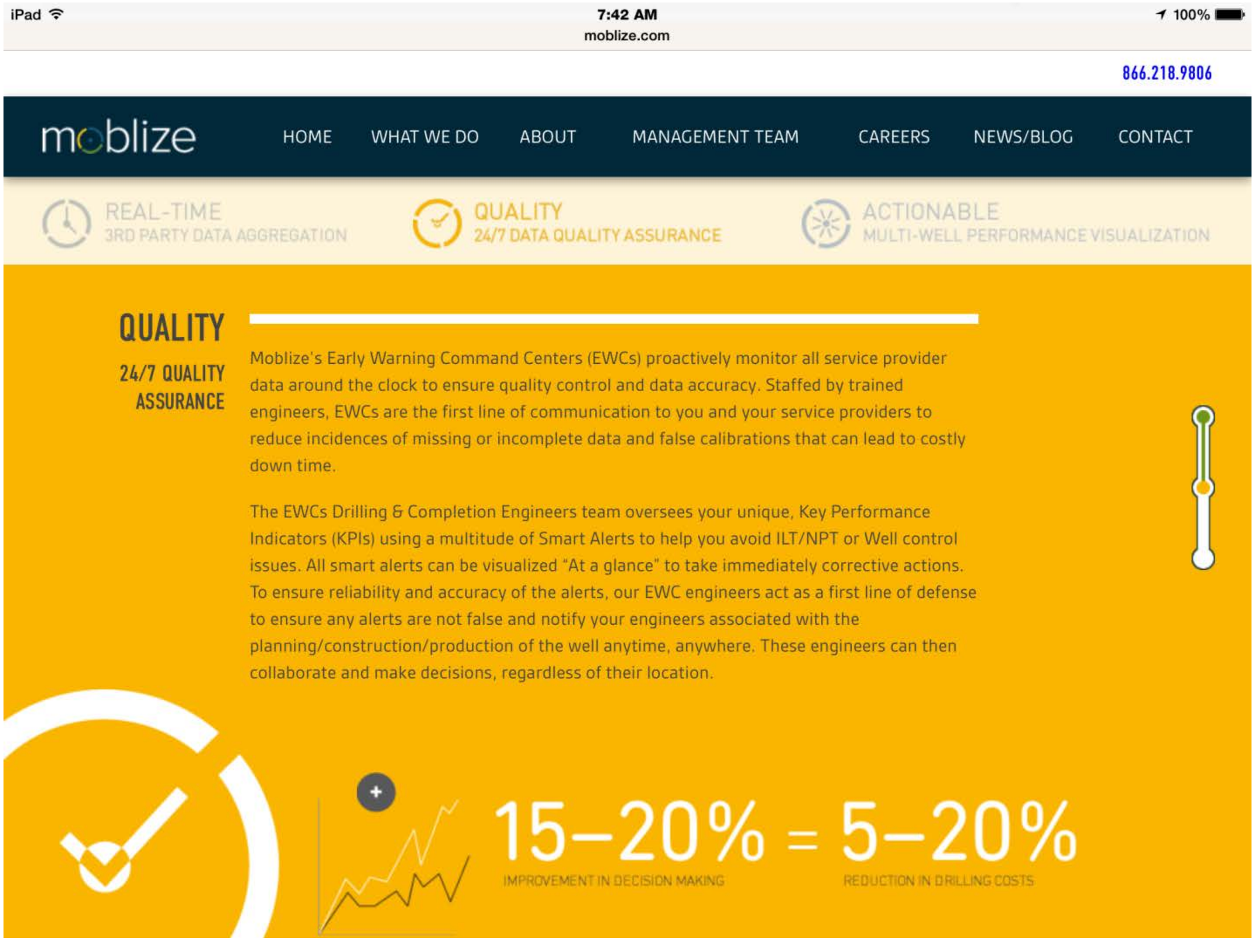

Figure 4. Screenshot from http://moblize.com/what-we-do/.

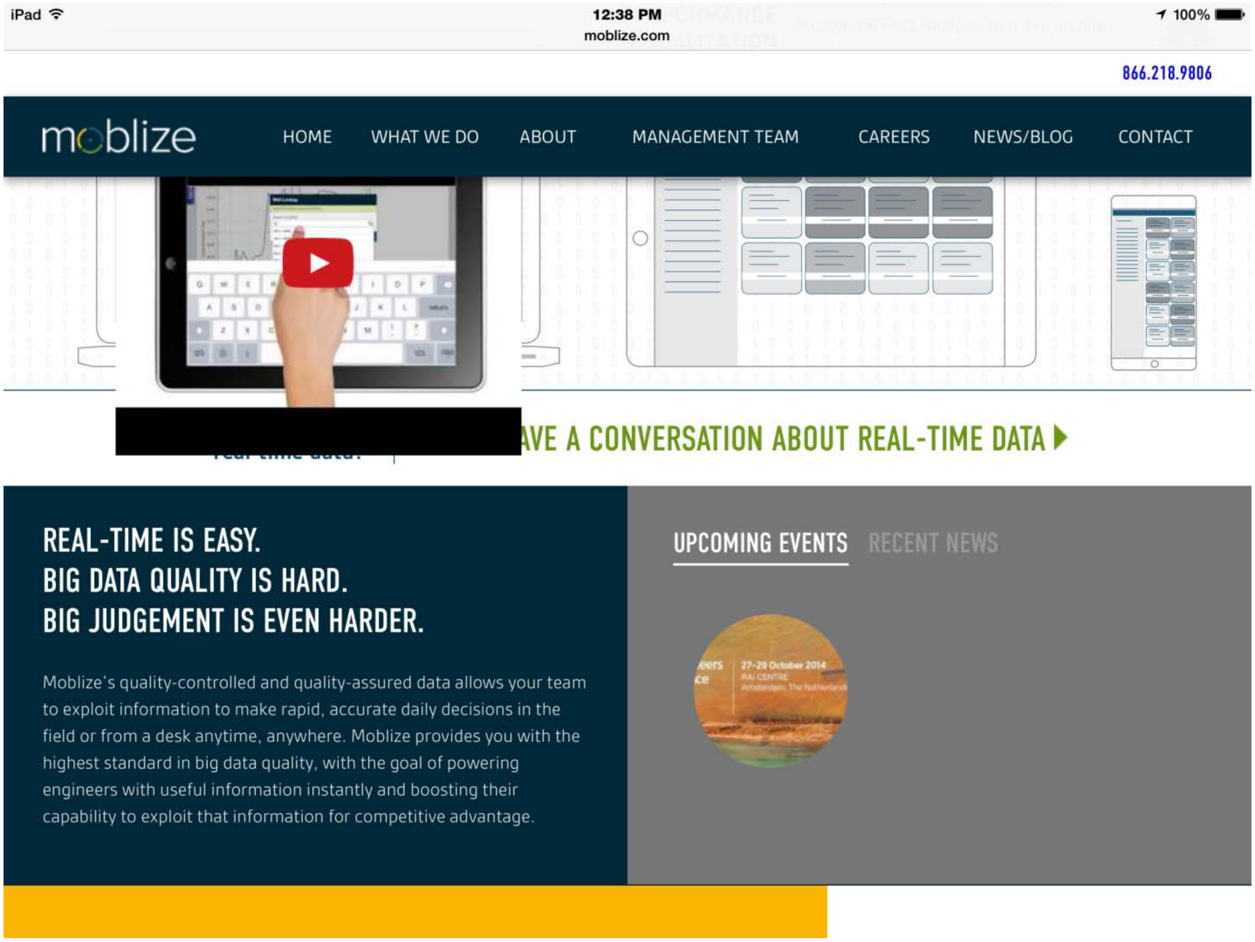

Figure 5. Screenshot from www.moblize.com.

CURRICULUM VITAE

NAME Michael **Nikolaou**

BIRTHDATE April 14, 1960

EDUCATION

PhD, Chemical Engineering, University of California, Los Angeles, 1989.
Diploma, Chemical Engineering, National Technical University, Athens, Greece, 1984.

PROFESSIONAL EXPERIENCE

Academic
Professor, Chemical Engineering Dept., University of Houston, (2007-present)
Associate Professor, Chemical Engineering Dept., University of Houston, 9/97-8/07.
Associate Professor, Chemical Engineering Dept., Texas A&M University, 9/95-8/97.
Visiting Scientist, Chemical Engineering Dept., MIT, Fall 1995.
Assistant Professor, Chemical Engineering Dept., Texas A&M University, 9/89-8/95
Teaching/Research Assistant, Chemical Engineering Dept., UCLA, 1/86-8/89.

Industrial
Process Engineer/Computer Specialist, Union Pacific Resources, Bryan, TX, Summer 1991.

PROFESSIONAL RECOGNITION

Chairmanship of National Meetings:

Session chair
AIChE Annual Meeting (several)
AIChE Spring Meeting (several)

Programming Committee member
American Control Conference (several)
ESCAPE 6
DYCOPS 5
ADCHEM 2003, 2009
FOCAPO 2008
IFAC World Congress, 2009
SPE Workshop on Bridging the Gap Between Reservoir Engineering and Facilities Design, 2012 (Organizing Committee)

International Programming Committee Chair
IFAC Conference on Control of Offshore Oil & Gas Drilling Operations, Trondheim, Norway (2012)

Awards:

Cullen College of Engineering Senior Faculty Research Excellence Award, 2010
"Professor Solution" in "Automation Avengers" educational campaign, ISA, 2008.
CAST Directors Poster Paper Award (with M. Darby), AIChE Annual Meeting, 2007
Top 2% Reviewer, Automatica (leading int'l journal on automatic control), 2007
Cullen College of Engineering Teaching Excellence Award, 2007
3rd place, Keck Center 2005 Annual Research Conference Poster Contest
Halliburton Energy Services Award, for paper SPE 71647 (co-authored with M. J. Economides and S. Sankaran)
TEES Fellow, Texas A&M, 1996, 1997
Professor of the Year, Texas A&M AIChE Student Chapter, 1994
Junior TEES Fellow, Texas A&M 1992
Teaching Assistant of the Year, UCLA 1988

TEACHING

Undergraduate

Numerical & Statistical Methods for Chemical Engineers (CHEE 3334, Junior)

Semester	**Fall 2006**	**Fall 2005**	**Fall 2004**	**Fall 2003**	**Fall 2002**	**Fall 2000**	**Fall 1999**	**Fall 1998**
Student evaluation score, (max=4) / Q.9 mean	**3.71**/3.11 = 1.20	**3.28**/3.21 = 1.02	**3.00**/3.05 = 0.98	**3.36**/3.17 = 1.06	**2.46**/3.06 = 0.80	**2.94**/3.15 = 0.93	**2.44**/3.19 = 0.76	**2.95/3.10 = 0.95**
Number of respondents	**21**	**32**	**33**	**44**	**40**	**29**	**25**	**31**

Process Dynamics & Control (CHEE 3367, Junior)

Semester	**Spr. 2014**	**Spr. 2013**	**Spr. 2012**	**Spr. 2011**	**Spr. 2010**	**Spr. 2009**	**Spr. 2008**	**Fall 2007**	**Spr. 2007**	**Spr. 2006**	**Spr. 2004**	**Spr. 2003**	**Spr. 2002**	**Spr. 2001**	**Spr. 2000**	**Spr. 1999**
Student evaluation score, (max=4,5) / Q.9,10 mean	4.43/ 4/17 = 1.06	4.49/ 4.29 = 1.05	4.10* /4.11 = 1.00	4.38* /4.13 = 1.06	4.33* /4.07 = 1.06	4.52* /4.05 = 1.12	4.47* /4.12 = 1.08	4.86* /3.86 = 1.26	3.37/ 3.17 = 1.06	3.56/ 3.26 = 1.10	3.19/ 3.17 = 1.01	3.32/ 3.15 = 1.05	2.64/ 2.97 = 0.89	3.12/ 3.01 = 1.04	3.36/ 3.04 = 1.10	3.38/ 3.02 = 1.12
Number of respondents	**45**	**39**	**42**	**45**	**40**	**31**	**19**	**15**	**28**	**24**	**37**	**25**	**27**	**26**	**29**	**34**

* Max = 5

Introduction to Computing for Engineers (CHEE/INDE/CIVE 1331, Freshman/Sophomore)

Semester	**Fall 2010**	**Fall 2009**	**Fall 2008**	**Fall 2002**
Student evaluation score, (max=4) / Q.9 mean	**4.15***/3.98 = 1.04	**4.52***/4.05 = 1.12	**4.12***/4.28 = 0.96	**2.38**/3.25 = **0.73**
Number of respondents	**34**	**31**	**49**	**33**

* Max = 5

Plant Economics (Senior)
Plant Design (Senior)

Chemical Engineering Thermodynamics I (Sophomore)
Statistical Methods in Chemical Engineering (Senior elective)
Statistical Quality Control Methods (Senior elective)
Written and oral communication for chemical engineers (Junior)

Graduate

Mathematical Methods in Chemical Engineering (CHEE 6331)

Semester	**Spring 2004**
Student evaluation score, (max=4) / Q.9,10 mean	**3.11**/3.27 = **0.95**
Number of respondents	**8**

Introduction to Mathematical Methods in Chemical Engineering (CHEE 6397/6330)

Semester	**Fall 2014**	**Fall 2013**	**Fall 2012**	**Fall 2011**
Student evaluation score, (max=5) / Q.9,10 mean	**4.68**/4.35 = **1.08**	**4.53**/4.31 = **1.05**	**4.57**/4.34 = **1.05**	**4.48**/4.38 = **1.02**
Number of respondents	**16**	**16**	**21**	**21**

Advanced Process Control (CHEE 6367/5367)

Semester	**Spring 2014**	**Spring 2012**	**Spring 2010**	**Spring 2008**	**Spring 2006**	**Spring 2004**	**Spring 2002 (Graduate & senior level)**
Student evaluation score, (max=4,5) / Q.9,10 mean	**4.80**/4.38 = **1.10**	**4.40***/4.39 = **1.00** **4.75**/4.19 = **1.13**	**4.56***/4.37 = **1.04**	**4.56***/4.28 = **1.07**	**3.42**/3.25 = **1.05**	**3.27**/3.30 = **0.99**	**3.33**/3.39 = **0.98** **3.17**/3.19 = **0.99**
Number of respondents	**20**	**25, 4**	**27**	**16**	**12**	**15**	**6, 2**

* Max = 5

SUPERVISION OF RESEARCH

PhD Theses Supervision:

Texas A&M University

1. Hasmet Genceli (currently with Bryan Research & Engineering)
2. Yong You (currently with Invensys)
3. Vijay Hanagandi (currently Principal of Applied Optimization, Inc.)
4. Harry Sarimveis (currently tenure-track faculty, National Technical University, Athens, Greece)
5. Wangyan (Charles) Feng (currently with Hewlett-Packard)
6. Manoj Shouche (currently with Montel Polyolefins)
7. Prem Vuthandam (currently with AspenTech)
8. Alex Schwarm (currently with Applied Materials)
9. Gabe Haarsma (currently with Shell)

University of Houston

10. S. Alper Eker – Spring 2001 (currently with General Electric Corporate R&D)
11. Haiyang Zhang – Spring 2002 (currently in China)
12. Dimitri Sagias – Fall 2003 (currently with Bayer, Baytown)
13. Pratik Misra – Spring 2003 (currently with Bayer, Baytown)
14. Luigi Saputelli – Spring 2003 (co-supervised with M. J. Economides) (currently with Halliburton)
15. Sathish Sankaran – Spring 2003 (co-supervised with M. J. Economides) (currently with Anadarko)
16. Nirmal Tatavalli, Ph.D – Summer 2007 (co-supervised with D. J. Economou) (currently with Shell)
17. Ankur Awasthi, PhD – Spring 2008 (currently with Halliburton)
18. Mark Darby, PhD – Fall 2008 (currently proprietor of CM*i*D Solutions, LLC)
19. Jan Einar Gravdal, PhD – Summer 2011 (co-supervisor; currently with IRIS, Norway)
20. Oeyvind Breyholtz, PhD – Summer 2011 (co-supervisor; currently with Statoil, Norway)
21. Ajay Singh, PhD – Summer 2012 (currently with Halliburton)
22. Pratik Bhagunde, PhD – Summer 2012 (currently with Astra-Zeneca)
23. Srimoyee Bhattacharya, PhD – Fall 2012 (currently with Shell)
24. Liv Carlsen, PhD – Fall 2012 (co-supervisor; currently with IRIS, Norway).
25. Hans-Peter Lohne, PhD – expected Summer 2013 (co-supervisor; currently at U. of Stavanger, Norway).
26. Shyam Panjwani, PhD – expected 2016
27. Yue Lin, PhD – expected 2016
28. Shobhit Misra, PhD – expected 2017

Masters Theses Supervision:
Texas A&M University

1. Yong You
2. Harry Sarimveis
3. Tong Zeng
4. Pablo Echeverria

University of Houston

5. Mohan Cherukuri
6. Diwakar Mantha
7. Cédric Oudinot (co-supervised with M. J. Economides)
8. Bilu Cherian (co-supervised with M. J. Economides)
9. Emre Serpen (co-supervised with Christine Ehlig-Economides)
10. Aysu Öztürk
11. Kevin Ziervogel
12. Aditya Kumar (eventually graduated with non-thesis MS)
13. Parag Kulkarni (ECE student) (co-supervisor) – Summer 2012
14. Kyle MacFarlan, 2014

PUBLICATIONS

1. Refereed Journal Publications

1. **Nikolaou**, M. and V. Manousiouthakis, "A Hybrid Approach to Nonlinear System Stability and Performance", *AIChE Journal,* **35,** 4, 559-572 (1989).

2. Manousiouthakis, V. and M. **Nikolaou**, "Analysis of Decentralized Control Structures for Nonlinear Systems", *AIChE Journal,* **35,** 4, 549-558 (1989).

3. **Nikolaou**, M. and V. Manousiouthakis, "Sensitivity Analysis of Optimal Control Policies for Batch Processes", *Chemical Engineering Communications* **97**, 27-45 (1990).

4. Fan, J. Y., M. **Nikolaou**, and R. E. White, "An Approach to Fault Diagnosis of Chemical Processes via Neural Networks", *AIChE J*. **39**, 1, 82-88 (1993).

5. You, Y., and M. **Nikolaou**, "Dynamic Process Modeling with Recurrent Neural Networks", *AIChE J*., **39**, 10, 1654-1667 (1993).

6. **Nikolaou**, M. and V. Hanagandi, "Input-Output Exact Linearization of Nonlinear Dynamical Systems Modeled by Recurrent Neural Networks", *AIChE J*., **39**, 11, 1890-1894 (1993).

7. Genceli, H., and M. **Nikolaou**, "Robust Stability Analysis of Constrained l_1-Norm Model Predictive Control", *AIChE J*., **39**, 12, 1954-1965 (1993).

8. Holtzapple, M. T., E. P. Ripley, and M. **Nikolaou**, "Saccharification, Fermentation, and Protein Recovery from AFEX-Treated Coastal Bermudagrass", *Biotechnology and Bioengineering*, **44**, 1112–1131 (1994).

9. **Nikolaou**, M., and V. Hanagandi, "Recurrent Neural Networks in Decoupling Control of Multivariable Nonlinear Systems", *Chem. Eng. Communications*, **136**, 201-216 (1995).

10. Vuthandam, P., H. Genceli, and M. **Nikolaou**, "Performance Bounds of Robust Model-Predictive Control", *AIChE J.*, **41**, 9, 2083-2097 (1995).

11. Genceli, H. and M. **Nikolaou**, "Design of Robust Constrained Nonlinear Model Predictive Controllers with Volterra Series", *AIChE J.*, **41**, 9, 2098-2107 (1995).

12. Hanagandi, V., H. Ploehn, and M. **Nikolaou**, "Solution of the Self-Consistent Field Model for Polymer Adsorption by Genetic Algorithms", *Chem. Eng. Sci.* , **51**, 7, 1071-1078 (1996).

13. Sarimveis, H., H. Genceli, and M. **Nikolaou**, "Design of Robust Non-Square Constrained Model Predictive Control", *AIChE J.*, **42**, 9, 2582-2593 (1996).

14. Genceli, H., and M. **Nikolaou**, "New Approach to Constrained Predictive Control with Simultaneous Model Identification", *AIChE J.*, **42**, 10, 2857-2869 (1996).

15. Hanagandi, V., and **Nikolaou**, M. "A Hybrid Approach to Global Optimization Using a Clustering Algorithm in a Genetic Search Framework," *Computers & Chem. Engng.*, **22,** 12, 1913-1925 (1998).

16. **Nikolaou**, M., and V. Hanagandi, "Nonlinearity Quantification and its Application to Nonlinear System Identification", *Chem. Eng. Comm.*, **166**, 1-33 (1998).

17. Shouche M., H. Genceli, P. Vuthandam, and M. **Nikolaou**, "Simultaneous Constrained Model Predictive Control and Identification of DARX Processes", *Automatica*, **34**, 12, 1521-1530 (1998).

18. Moridis, G. J., M. **Nikolaou**, and Y. You, "The Use of Wavelet Transforms in the Solution of Two-Phase Flow Problems", *SPE J.*, **29144**, 169-178 (1996).

19. Shouche, M., H. Genceli, and M. **Nikolaou**, "Dependence of Model Predictive Control and Identification Performance on On-Line Optimization Techniques", *Computers Chem. Engng.,* **26**, 9, 1241-1252 (2002).

20. Vuthandam, P., and M. **Nikolaou**, "Constrained Model Predictive Control and Identification: A Weak Persistent Excitation Approach", *AIChE J.*, **43**, 9, 2279-2288 (1997).

21. **Nikolaou**, M., and P. Vuthandam, "FIR Model Identification: Achieving Parsimony through Kernel Compression with Wavelets", *AIChE J.*, **44**, No. 1, 141-150 (1998).

22. Schwarm, A., and M. **Nikolaou**, "Chance Constrained Model Predictive Control", *AIChE Journal*, **45**, 8, 1743-1752 (1999).

23. Eker, S. A., and M. **Nikolaou**, "Adaptive Control through On-line Optimization: The MPCI Paradigm and Variants", *Appl. Math. And Comp. Sci.*, **9**, 1, 101-128 (1999).

24. **Nikolaou**, M., "Identification and Adaptive Control", *Comp. Chem. Eng., special issue on NSF/NIST Vision 2020 Workshop*, 23/2, pp. 215 - 225, (1998).

25. Zhang, H., Y. Peng, M. **Nikolaou**, "Development of a Data Driven Dynamic Model for a Plasma Etching Reactor", *J. Vac. Sci. Tech.* B 20 (3): 891-901 MAY-JUN 2002.

26. Eker, S. A., and M. **Nikolaou**, "Linear Control of Nonlinear Systems - The Interplay between Nonlinearity and Feedback", *AIChE J.*, 48 (9): 1957-1980 SEP 2002.

27. Misra P, **Nikolaou** M, “Input design for model order determination in subspace identification”, *AICHE J* 49 (8): 2124-2132 AUG 2003.

28. **Nikolaou** M, Misra P, “Linear control of nonlinear processes: recent developments and future directions”, *COMPUT CHEM ENG* 27 (8-9): 1043-1059 SEP 15 2003.

29. V. H. Tam, A. N. Schilling, and M. **Nikolaou**, "Modelling time-kill studies to discern the pharmacodynamics of meropenem," *Journal Of Antimicrobial Chemotherapy*, vol. 55, pp. 699-706, 2005.

30. V. H. Tam and M. **Nikolaou**, "Mathematical modelling of resistance emergence," *Journal Of Antimicrobial Chemotherapy*, vol. 56, pp. 983-983, 2005.

31. M. **Nikolaou**, P. Misra, V. H. Tam, and A. D. Bailey, "Complexity in semiconductor manufacturing, activity of antimicrobial agents, and drilling of hydrocarbon wells: Common themes and case studies," *Computers & Chemical Engineering*, vol. 29, pp. 2266-2289, 2005.

32. L. Saputelli, M. **Nikolaou**, and M. J. Economides, "Self-learning reservoir management," *SPE Reservoir Evaluation & Engineering*, vol. 8, pp. 534-547, 2005.

33. M. **Nikolaou** and V. H. Tam, "A new modeling approach to the effect of antimicrobial agents on heterogeneous microbial populations," *Journal of Mathematical Biology*, vol. 52, pp. 154-182, 2006.

34. **Nikolaou**, M., "Control of Snack Food Manufacturing Systems: Potato chips and micro-chips are more similar than commonly believed", *IEEE Control Systems Magazine*, **featured on cover of** special issue on process control, 26 (4) : 40-54, 2006.

35. L. Saputelli, M. **Nikolaou** b, and M.J. Economides, "Real-Time Reservoir Management: A Multi-Scale Adaptive Optimization and Control Approach", *J. Computational Geosciences*, invited publication for Special Issue on Closed-Loop Reservoir Management, 10, 61-96, 2006.

36. Darby, M. L., and M. **Nikolaou**, "A Parametric Programming Approach to Moving Horizon State Estimation", *Automatica*, 43 (5): 885-891, 2007.

37. **Nikolaou** M, Schilling AN, Vo G, et al., "Modeling of microbial population responses to time-periodic concentrations of antimicrobial agents" ANNALS OF BIOMEDICAL ENGINEERING 35 (8): 1458-1470 AUG 2007.

38. Tam, V. H.; Schilling, A. N.; Poole, K.; **Nikolaou**, M., Mathematical modelling response of Pseudomonas aeruginosa to meropenem. *Journal Of Antimicrobial Chemotherapy* **2007,** 60, (6), 1302-1309.

39. Tam, V. H.; Vo, G.; Kabbara, S.; **Nikolaou**, M., Pharmacodynamics of gentamicin against Pseudomonas aeruginosa: modelling bacterial response to drug-selective pressures. *International Journal Of Antimicrobial Agents* **2007,** 29, S87-S88.

40. Tam, V. H.; Ledesma, K. R.; Vo, G.; Kabbara, S.; Lim, T. P.; **Nikolaou**, M., Pharmacodynamic Modeling of Aminoglycosides against Pseudomonas aeruginosa and Acinetobacter baumannii: Identifying Dosing Regimens To Suppress Resistance Development. *Antimicrobial Agents And Chemotherapy* **2008,** 52, (11), 3987-3993.

41. Lim, T. P.; Ledesma, K. R.; Chang, K. T.; Hou, J. G.; Kwa, A. L.; **Nikolaou**, M.; Quinn, J. P.; Prince, R. A.; Tam, V. H., Quantitative assessment of combination antimicrobial therapy against multidrug-resistant Acinetobacter baumannii. *Antimicrobial Agents And Chemotherapy* **2008,** 52, (8), 2898-2904.

42. Darby, M. L. and M. **Nikolaou**, Multivariable system identification for integral controllability, *Automatica*, 45(10): 2194-2204, **2009**.

43. W. J. Foster, N. Dowla, S. Y. Joshi, M. **Nikolaou**, "The fluid mechanics of scleral buckling surgery for the repair of retinal detachment", *Graefes Arch Clin Exp Ophthalmol*, DOI 10.1007/s00417-009-1198-z, SEP 2009. (ONLINE).

44. M. **Nikolaou**, "Optimizing the Logistics of Compressed Natural Gas Transportation by Marine Vessels", *Journal of Natural Gas Science and Engineering*, 2(1), 1-20, **2010**.

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65. Tan, MW, Lye, DC, Ng, TM, **Nikolaou**, M, and Tam, VH (2014) "Mathematical Model To Quantify the Effects of Risk Factors on Carbapenem-Resistant Acinetobacter baumannii", *Antimicrobial Agents and Chemotherapy*, 58(9): 5239-5244.

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67. Kulkarni, P., M. L. Darby, and M. **Nikolaou**, "Adaptive Design of Experiments for Identification of Dynamic Models subject to Integral Controllability", *Automatica* (in preparation).

68. Bhattacharya, S., and M. **Nikolaou**, (2013). "Optimization of hydraulic fracturing for shale gas production", *SPE Journal,* SJ-1014-0006 (in print).

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2. Book Chapters

1. **Nikolaou**, M., and Y. You, "Use of Wavelets for Numerical Solution of Differential Equations", *Wavelet Applications in Chemical Engineering*, B. Joseph and R. Motard (Editors), 209-274, Kluwer (1994).

2. Hanagandi, V., and M. **Nikolaou**, "Applications of Genetic Algorithms in Chemical Engineering", *Practical Handbook of Genetic Algorithms*, Lance Chambers Ed., Volume 2, 221-252, CRC Press (1995).

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4. **Nikolaou**, M., “Selecting Optimal Dosing Regimens for Antimicrobial Agents: A Data-Driven Modeling Approach”, *Optimization in Medicine and Biology*, G. Lim (Editor), Taylor & Francis, (2007).

5. M. **Nikolaou**, "Compressed Natural Gas" in *Advanced Natural Gas Engineering*, X. Wang and M. J. Economides, Gulf Publishing, 2009.

3. Major Reports

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4. Refereed Conference Proceedings Publications

1. Manousiouthakis, V. and M. **Nikolaou**, "On the Nonlinear Block Relative Gain", *Proceedings of the American Control Conference*, Seattle, WA, 2120-2125 (1987).

2. **Nikolaou**, M. and V. Manousiouthakis, "A Hybrid Approach to Nonlinear System Theory", *Proceedings of the 26th IEEE Conference on Decision and Control*, Century City, CA, 2127-2132 (1987).

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6. **Nikolaou**, M. and H. Genceli, "Establishing Performance Targets for Model Predictive Control Systems through off-line Optimization", *Proceedings of the American Control Conference*, Boston, MA, 1822-1823 (1991).

7. **Nikolaou**, M., and H. Sarimveis, "Process Modeling with Recurrent Neural Networks", *ANNIE 91 Proceedings* (1991).

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20. Sarimveis, H., H. Genceli, and M. **Nikolaou**, "Design of Robust Non-Square Constrained Model Predictive Control", to be included in *European Symposium on Computer-Aided Process Engineering Proceedings*, Rhodes, Greece (May, 1996).

21. Genceli, H., and M. **Nikolaou**, "A New Approach to Constrained Predictive Control with Simultaneous Model Identification", to be included in *European Symposium on Computer-Aided Process Engineering Proceedings*, Rhodes, Greece (May, 1996).

22. **Nikolaou**, M., "Directions in Computer-Aided Process Engineering", *AIChE World Congress Proceedings*, San Diego, CA (1996).

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25. Sankaran, S., M. **Nikolaou**, and M. J. Economides, "Fracture Geometry and Vertical Migration in Multilayered Formations from Inclined Wells", paper SPE 63177, *SPE Annual Meeting*, Dallas (2000).

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27. Saputelli, L., B. Cherian, K. Grigoriadis, M. **Nikolaou**, C. Oudinot, G. Reddy, M. J. Economides, and C. Ehlig-Economides, "Integration of Computer-Aided High-Intensity Design with Reservoir Exploitation of Remote and Offshore Locations", SPE paper 64621 and *SPE J.,* (2000).

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31. **Nikolaou**, M., and D. Sagias, "Model Identification: Capabilities and Limits", AspenWorld 2002 (Invited Talk).

32. Misra, P., M. **Nikolaou**, and A. D. Bailey, III, "Application of reduced-rank multivariate methods to the analysis of spatial uniformity of Silicon wafer etching", ADCHEM 2003, Hong Kong, 2003 (held in January 2004 because of SARS.)

33. L. Saputelli, M. **Nikolaou**, M. Economides, V. Kelessidis, "Real-Time Decision Making for Value Creation while Drilling", SPE/IADC Middle East Drilling Technology Conference & Exhibition Abu Dhabi, UAE, 20-22 October (2003).

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35. **Nikolaou**, M., and V. H. Tam, "Modeling the effect of antibiotics on bacterial populations of distributed resistance: A system approach" FOSBE 2005, Santa Barbara, CA (2005).

36. **Nikolaou**, M., A. S. Cullick, and L. Saputelli, "Production Optimization: A Moving Horizon Approach", SPE 99358, Intelligent Energy 2006, Amsterdam, NL (2006).

37. **Nikolaou**, M., L. Saputelli, G. Mijares, S. Sankaran , and L. Reis "A Consistent Approach toward Reservoir Simulation at Different Time Scales", SPE 99451, Intelligent Energy 2006, Amsterdam, NL (2006).

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40. L. A. Carlsen, G. Nygaard, J. E. Gravdal, M. **Nikolaou**, J. Schubert, Performing the Dynamic Shut-In Procedure Because of a Kick Incident When Using Automatic Coordinated Control of Pump Rates and Choke-Valve Opening, SPE 113693-MS (2008).

41. A. Awasthi, S. Sankaran, M. **Nikolaou**, L. Saputelli, G. Mijares, "Short-Term Production Optimization by Automated Adaptive Modeling and Control", SPE 112239-MS (2008).

42. A. Awasthi, S. Sankaran, M. **Nikolaou**, L. Saputelli, G. Mijares, "Meeting the Challenges of Real-Time Production Optimization—A Parametric Model-Based Approach", SPE 111853-MS (2008).

43. Darby, M. and M. **Nikolaou**, "Multivariable System Identification for Integral Controllability – Computational Issues", ADCHEM 2009, Instanbul, Turkey (2009).

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45. M. **Nikolaou**, M. J. Economides, X. Wang, and M. Marongiu-Porcu, "Distributed Compressed Natural Gas Sea Transport" paper OTC-19738-MS, Offshore Technology Conference, Houston, TX 2009.

46. Ø. Breyholtz, G. Nygaard, and M. **Nikolaou**, "Advanced Automatic Control for Dual-Gradient Drilling", paper SPE 124631, SPE Annual Technical Conference and Exhibition, New Orleans, 2009.

47. J. E. Gravdal, M. **Nikolaou**, Ø. Breyholtz, and L. A. Carlsen, "Improved Kick Management During MPD by Real-Time Pore-Pressure Estimation", paper SPE 124054-MS, SPE Annual Technical Conference and Exhibition, New Orleans, 2009.

48. Ø. Breyholtz, G. Nygaard, and M. **Nikolaou**, "Automatic Control of Managed Pressure Drilling", invited talk, American Control Conference, June 2010.

49. Ø. Breyholtz, G. Nygaard, H. Siahaan, M. **Nikolaou**, " Managed Pressure Drilling: A Multi-Level Control Approach", paper SPE 128151, Intelligent Energy, Amsterdam, March 2010.

50. Bhattacharya, S. and M. **Nikolaou** (2011a). “Optimal Fracture Spacing And Stimulation Design For Horizontal Wells In Unconventional Gas Reservoirs”. SPE-147622-MS, SPE Annual Technical Conference and Exhibition. Denver, Colorado.

51. Bhattacharya, S. and M. **Nikolaou** (2011b). “Using Data From Existing Wells To Plan New Wells in Unconventional Gas Field Development”. SPE-147658-MS, Canadian Unconventional Resources Conference. Calgary, Alberta.

52. Moridis, G. J., H. Kuzma-Anderson, M. T. Reagan, T. A. Blasingame, R. Santos, K. Boyle, C. M. Freeman, D. Ilk, Y. W. Wang, S. C. Pullman, S. Bhattacharya and M. **Nikolaou** (2011). “SeTES: A Self-Teaching Expert System for the Analysis, Design, and Prediction of Gas Production From Unconventional Gas Resources”. SPE-149485-MS, Canadian Unconventional Resources Conference. Calgary, Alberta, Canada, 2011, SPE.

53. **Nikolaou**, M. “Computer-Aided Process Engineering in Oil and Gas production”, Invited presentation at CPC VIII, Savannah, GA, Jan 2012.

54. Bravo, C. E., L. A. Saputelli, F. I. Rivas, A. G. Perez, M. **Nikolaou**, G. Zangl, N. d. Guzman, S. D. Mohaghegh and G. Nunez (2012). “State-of-the-Art Application of Artificial Intelligence and Trends in the E&P Industry: A Technology Survey”. SPE-150314-MS, SPE Intelligent Energy International. Utrecht, The Netherlands, Society of Petroleum Engineers.

55. Saputelli L., Bravo C., Nikolaou M., Lopez C., Cramer R., Mochizuki T., Moricca G. (2013). “Best practices and lessons learned after 10 years of digital oilfield (DOF) implementations”, SPE 167269.

56. C. Wreden, J.T. Watters, R. Giroux, M. Nikolaou, K. Macfarlan, D.A. Richardson (2014) Deepwater Reverse-Circulation Primary Cementing: Applicability and Technical Path Forward for Implementation, OTC 25194-MS.

57. HB. Siahaan, EH Vefring, M **Nikolaou**, , JE. Gravdal, Evaluation of Coordinated Control During Back Pressure MPD Operations, Evaluation of Coordinated Control During Back Pressure MPD Operations, SPE 169205.

Papers at Technical Meetings without Conference Proceedings:

Regular presenter annually at AIChE National Meetings

Other Publications:

1. M. J. Economides, and M. **Nikolaou**, "Energy: Facts and Myths", *Kathimerini*, (major Greek daily; in Greek), June 2009.

2. M. J. Economides, and M. **Nikolaou**, "Greece's great opportunity", *Kathimerini*, (major Greek daily; in Greek), April 2009.

3. Economides, M., N. Mitsos, and M. **Nikolaou**, “Natural Gas and Geopolitical Implications” (in Greek) *Phileleftheros*, Cyprus daily, January 2011.

4. Economides, M., and M. **Nikolaou**, “The Future of Natural Gas in Cyprus” (in Greek), *O Politis (Citizen)*, Cyprus daily, October 2011.

Invited Seminars:

Lawrence Berkeley National Laboratory, 1994.
U. of Texas, Austin, 1995.
U. of Massachusetts, Amherst, 1995.
Chemical Process Control Conference, Invited Talk, Tahoe City, 1996 (leading quinquennial international event on Chemical Process Control)
Northwestern University, 1995.
Rice University, 1996.
U. of Houston, 1995, 1997.
NSF/NIST Workshop, New Orleans, 1998.
NSF Workshop on Nonlinear Model Predictive Control, Ascona, Switzerland, 1998.
Texas Tech, Lubbock, TX, 2000.
Texas-Wisconsin Modeling & Control Consortium, Invited Talk, U. of Texas, Austin, 2001.
AspenWorld, Invited Talk, 2002.
“Advanced Computer Control of Chemical Processes: A Critical Overview of Historical and Technical Developments”, AIChE South TX Section, January 2004.
“The Role of Academia” GEMI Workshop, April 3, 2003.
“Industry/University Collaborative Technology Development and Dissemination”, Invited talk, AspenTech, 3/9/2004.

"Advanced Computer Control of Chemical Processes: A Critical Overview of Historical and Technical Developments", invited talk, AIChE South TX Section, 1/12/2004.

"Production Optimization: A Case for Intelligent Oilfield Operations", invited talk, ConocoPhillips, Houston, TX, 3/14/2005.

"Production Optimization: A Case for Intelligent Oilfield Operations", invited talk, Landmark Graphics, Houston, TX, 2/21/2005.

"Intelligent Oilfield Operations", invited talk, Pontifícia Universidade Católica do Rio de Janeiro, Brazil, 10/8/2004.

"A New Mathematical Modeling Approach to the Effect of Antimicrobial Agents to Heterogeneous Microbial Populations", Methodist Hospital Workshop, November 9, 2005.

"Modeling for making micro-chips, killing pathogens, and drilling hydrocarbon wells: Common themes & case studies", University of Oklahoma, October 20, 2005.

Distinguished Speaker, SPE FIRST ANNUAL EMERGING ENGINEERS CONFERENCE, Houston, TX, May 5, 2005.

"Systems, Control and Optimization" Workshop: Intelligent Wells – A Primer, University of Houston, August 30, 2006.

"Systems, Control and Optimization" Workshop: Instituto Colombiano del Petroleo, October 18, 2006.

" Control-Relevant Identification of Ill-Conditioned Multivariable Systems", ExxonMobil, Baytown, TX, March 8, 2007.

" A New Mathematical Modeling Approach to the Effect of Antimicrobial Agents on Microbial Populations of Distributed Resistance: Theory and Experiments", Mechanical Engineering Dept., UH, April 2007.

"Making the Business Case for Collaborative Technology Investment", Future Fields Summit, London, UK, May 9, 2007.

"Experience from Automation Technologies in Other Industries and Their Transfer to the Petroleum Industry", Real-Time Optimization Advanced Technical Workshop by SPE, Houston, TX, January 22, 2007.

"Experience from Automation Technologies in Other Industries and Their Transfer to the Petroleum Industry", Drilling Workshop organized by the International Research Institute of Stavanger, Rice U., Houston, TX, May 7, 2008.

"Experience from Automation Technologies in Other Industries and Their Transfer to the Petroleum Industry", International Research Institute of Stavanger, Norway, June 1, 2008.

(KEYNOTE) "A Holistic View to Natural Gas Production", Risavika Natural Gas Center opening, Stavanger, Norway, August 25, 2008.

"Modeling: Art, Science and Engineering", University of British Columbia, Vancouver, Canada, March 19, 2009.

"Compressed Natural Gas: Present Status and Future Challenges", First Trondheim Gas Technology Conference", October 2009.

"Energy Geopolitics", ELIAMEP, Athens, Greece, May 2009.

"Control hierarchy for drilling automation", International Research Institute of Stavanger, Bergen, Norway, June 2009.

"Modeling: Art, Science, and Engineering", National Technical University, Athens, Greece, May 2009.

"Automation Avengers", ISA Annual Conference (education presentation to 600 HISD students), Houston, October 2009.

"Control system integration for offshore drilling operations", invited presentation at International Research Institute of Stavanger, Bergen, Norway, June 2010.

"Corn Ethanol", invited presentation, Celanese, Houston, TX, Dec. 2010**.**

"Modeling: Art, Science, and Engineering", Imperial College, London, UK (June, 2011). (Invited lecture on the occasion of being External PhD Examiner).

"Improving Safety through Process Automation", International Research Institute of Stavanger (IRIS) Bergen, Norway (2012).

"Liquefied Natural Gas", Mare Forum, Pafos, Cyprus (2012).

"Monetizing Natural Gas: GTW, GTL, LNG, and CNG", Mare Forum, Pafos, Cyrpus (2013)

"Monetizing Natural Gas: GTW, GTL, LNG, and CNG", Mare Forum, Athens, Greece (2014)

Patents:

Economides, Michael J.; Deeg, Wolfgang F. J.; Valko, Peter; **Nikolaou**, Michael; and Sankaran, Sathish, METHOD FOR STRESS AND STABILITY RELATED MEASUREMENTS IN BOREHOLES, U.S. Patent 6,834,233, 2004.

Tam, V. H., and M. **Nikolaou**, MODELING OF MICROBIAL (TUMOR) ADAPTATION TO ANTIMICROBIAL (CYTOTOXIC) AGENTS, D6678PCT; PCT/US2006/036458 (pending).

Gerardo Mijares; Alejandro Garcia; Sathish Sankaran; Jose Rodriguez; Luigi Saputelli; Ankur Awasthi; and Michael **Nikolaou**, SYSTEMS AND METHODS FOR OPTIMIZATION OF REAL TIME PRODUCTION OPERATIONS, US Patent No. 8,396,826, March 12, 2013.

Ajay P. Singh; Michael Nikolaou; Luigi Saputelli; Marko Maucec, METHODS AND SYSTEMS TO HISTORY MATCH RESERVOIR MODEL FOR IMPROVED PREDICTIVE CAPABILITY, Disclosure made to Intellectual Property Law Department, Halliburton, docket number 2013-IP-070903.

FUNDED RESEARCH

Grants:

NSF, "Comprehensive Design Methodology for Nonlinear Controllers", $55K (Initiation), 1990-1993.
Frito-Lay, "Control of Snack Food Processes", $105K, 1992-1994.
ARP, "Numerical Methods for Differential Equations with Wavelets", $39K, 1991-1993.
ATP-D, "Novel Control Methodology for Snack Food Extrusion Cooking", $150K, 1993-1996.
Frito-Lay, "Novel Control Methodology for Snack Food Extrusion Cooking", $136K, 1993-1996.
Shell Development, unrestricted, $20K/year + student summer support, 1992-1994 and 1997-2003.
DoE (through Lawrence Berkeley Lab), "Wavelets for Solution of Differential Equations Describing Underground Reservoir Two-Phase Flow", $30K, 1993-1994.
TXDoT (through TTI), "Traffic Air Pollution Effects of Elevated, Depressed, and at-Grade Level Freeways in Texas", $100K, 1993-1996.
Frito-Lay, unrestricted, $150K, 1996-2000.
NSF, "Design of Model Predictive Control Systems with Enhanced Autonomy", $180K, 1997-2001.
Internal grants at Texas A&M University and UH.
Halliburton, "Development of a Novel Methodology for Stress and Stability Related Measurements in Boreholes", $325K, 1998-2000 (with M. Economides and P. Valko).
NSF/Lam Research Corporation, "A Study on Plasma Etching Yield Improvements through a Faculty-in-Industry Internship", $58,000, 6-10/2001.
Lam Research Corporation, Unrestricted, $25,000/year, 2001-2003.
Kellogg Brown and Root, Unrestricted, $30,000+/year, 2001-2004; $40,000/year, 2006.
NSF, "Adaptive design of experiments for optimal uniformity in semiconductor manufacturing", $340K, 1/1/2003 – 12/31/2006 (CTS – 0227232) (with D. J. Economou).
American Chemical Society, Petroleum Research Fund, "A New Approach to High-Performance Drilling of Hydrocarbon Wells", $80K, 1/1/2004-8/31/2007.
Johns Hopkins, CAAT, "Development of a mathematical model to predict bacterial response to antimicrobial agents", $18K, 1/1/2005-12/31/2005.
eSimulation, Unrestricted, $20,000, 2006.
Landmark/Halliburton, "Real-time production optimization", $25,000, 1/1-31/12/2007.
Astra Zeneca, "Pharmacodynamics of antibiotics on resistant bacterial populations", $219,393 7/16/07 to 7/15/09 (with V. H. Tam),
National Science Foundation, "Development and experimental testing of a new approach to modeling the effect of antimicrobial agents on heterogeneous microbial populations", $400K, 1/1/2008-12/31/2010. (with V. H. Tam)
Research Partnership to Secure Energy for America (RPSEA), A Self-Teaching Expert System For The Analysis, Design And Prediction Of Gas Production From Shales, $753,060 for M. **Nikolaou** (~$3,000,000 project total).
Shell Global Solutions, "Analysis of Real-time optimization", $124180, 9/1/2007-8/31/2009.
MaxWells, "Intelligent Drilling of Hydrocarbon Wells" Support for two visiting PhD students from International Research Institute of Stavanger (IRIS) Norway.
Unrestricted grant, Optima PowerWare, $44K, 2009, 2011.
Unrestricted grant to Chemical & Biomolecular Engineering Dept. for one PhD student scholarship, Bayer Baytown, $90K, 2008-2010.
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1995-97	Texas A&M U.	Council of Principal Investigators
1994-97	Ch.E. Dept., Texas A&M	Undergraduate Curriculum Committee
1996-97	Ch.E. Dept., Texas A&M	Graduate Curriculum Committee
1996-97	Ch.E. Dept., Texas A&M	Web site team leader
1998-	CoE, UH	ABET Steering Committee
1999-2001	Ch.E. Dept., UH	Director of Graduate Studies
2001-2006	Ch.E. Dept., UH	AIChE Student Chapter Advisor
2002-	CoE, UH	Graduate Standards Committee
2002-2007	Ch.E. Dept., UH	MChE Program Director
2003-2007	CoE, UH	Communications Committee
2003-2007	CoE, UH	Computing Facilities Committee
2005-	Ch.E. Dept., UH,	ABET Outcomes Assessment Committee Chair,
2007-2008	Ch.E. Dept., UH	International ChE graduate student admissions
2007-2010	UH	Graduate and Professional Studies Council
2007-2010	UH	UH Teaching Excellence Awards Committee
2007-	UH	SACS Instructional Effectiveness Committee
2007-	Texas A&M	Advisory Board, ChE Curriculum Reform Project (NSF)
2005-	Process Technology Dept., Houston Community College, Advisory Board,	
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Society of Petroleum Engineers
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Spanish & French (engineering material reading ability)
Greek (mother tongue)

Personal

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US006892812B2

(12) **United States Patent**
Niedermayr et al.

(10) **Patent No.: US 6,892,812 B2**
(45) **Date of Patent: May 17, 2005**

(54) **AUTOMATED METHOD AND SYSTEM FOR DETERMINING THE STATE OF WELL OPERATIONS AND PERFORMING PROCESS EVALUATION**

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(73) Assignee: **Noble Drilling Services Inc.**, Sugar Land, TX (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(52) **U.S. Cl.** **166/250.15**; 166/53; 175/24; 175/40; 702/9

(58) **Field of Search** 175/24–38, 40; 166/250.15, 53; 702/9; 340/854.1, 856.1, 856.3; 73/152.43, 152.19

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Primary Examiner—David Bagnell
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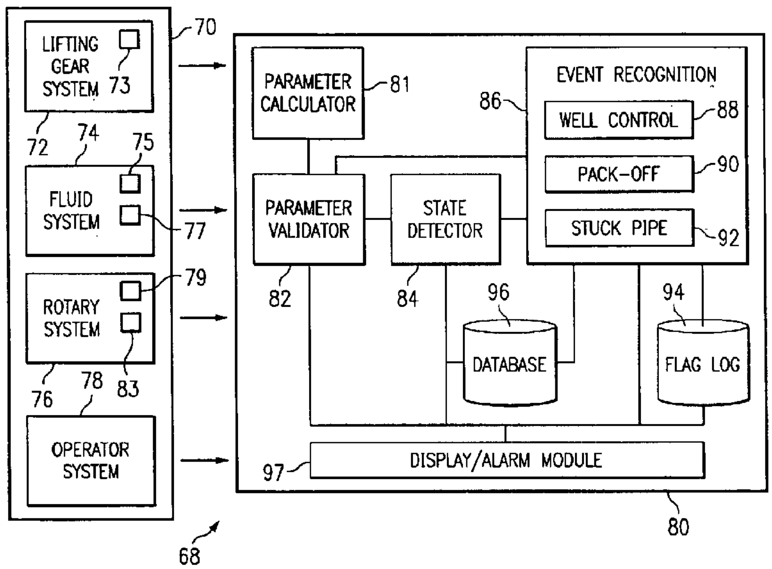
(74) *Attorney, Agent, or Firm*—Baker Botts L.L.P.

(57) **ABSTRACT**

An automated method and system for determining the state of a drilling or other suitable well operations includes storing a plurality of states for the well operation. Mechanical and hydraulic data is received for the well operation. Based on the mechanical and hydraulic data, one of the states is automatically selected as the state of the well operation. Process evaluation may be performed based on the state of the well operation.

115 Claims, 6 Drawing Sheets



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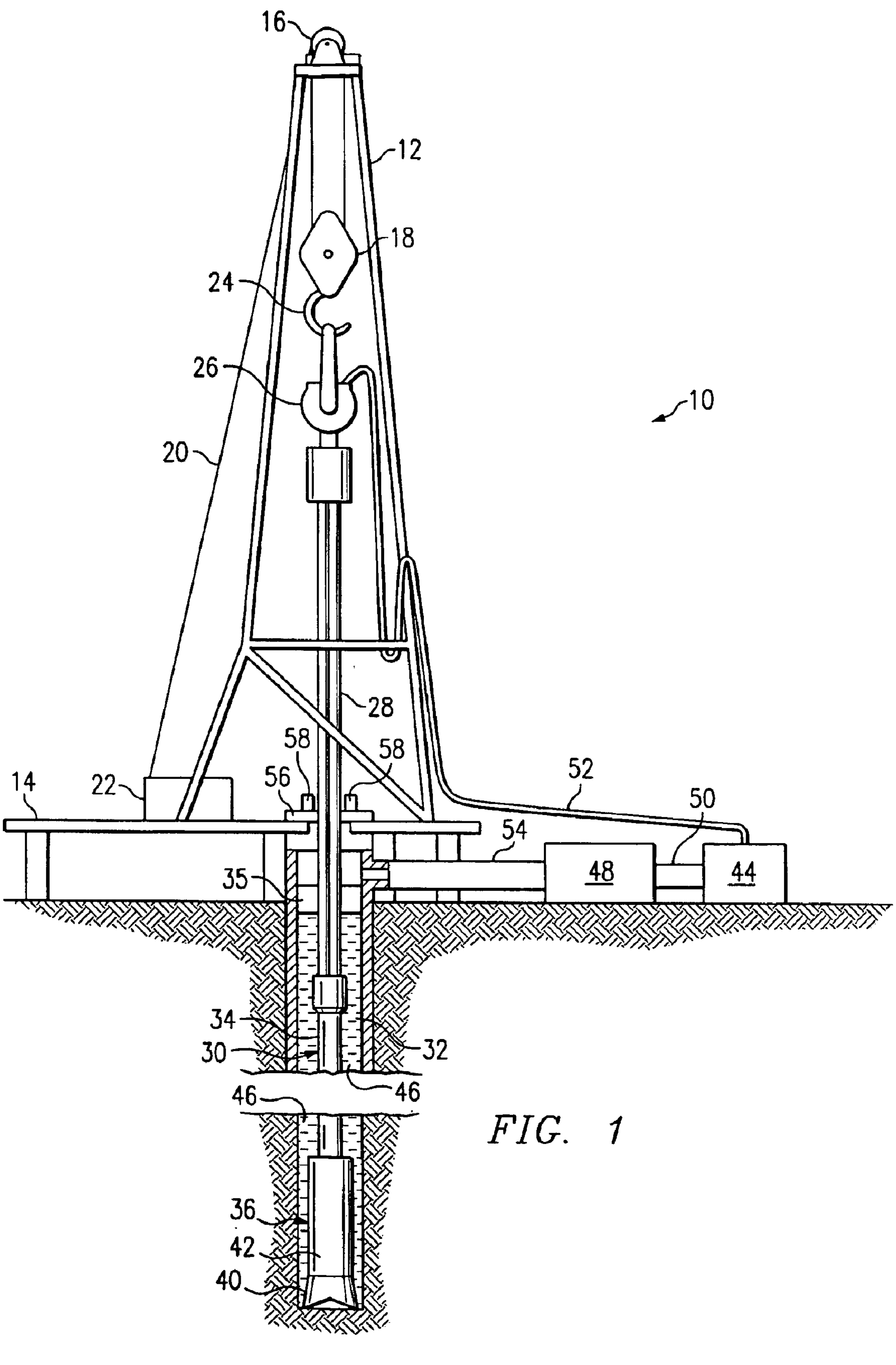
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12
18
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20
28
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30
32
46
46
36
42
40

FIG. 1

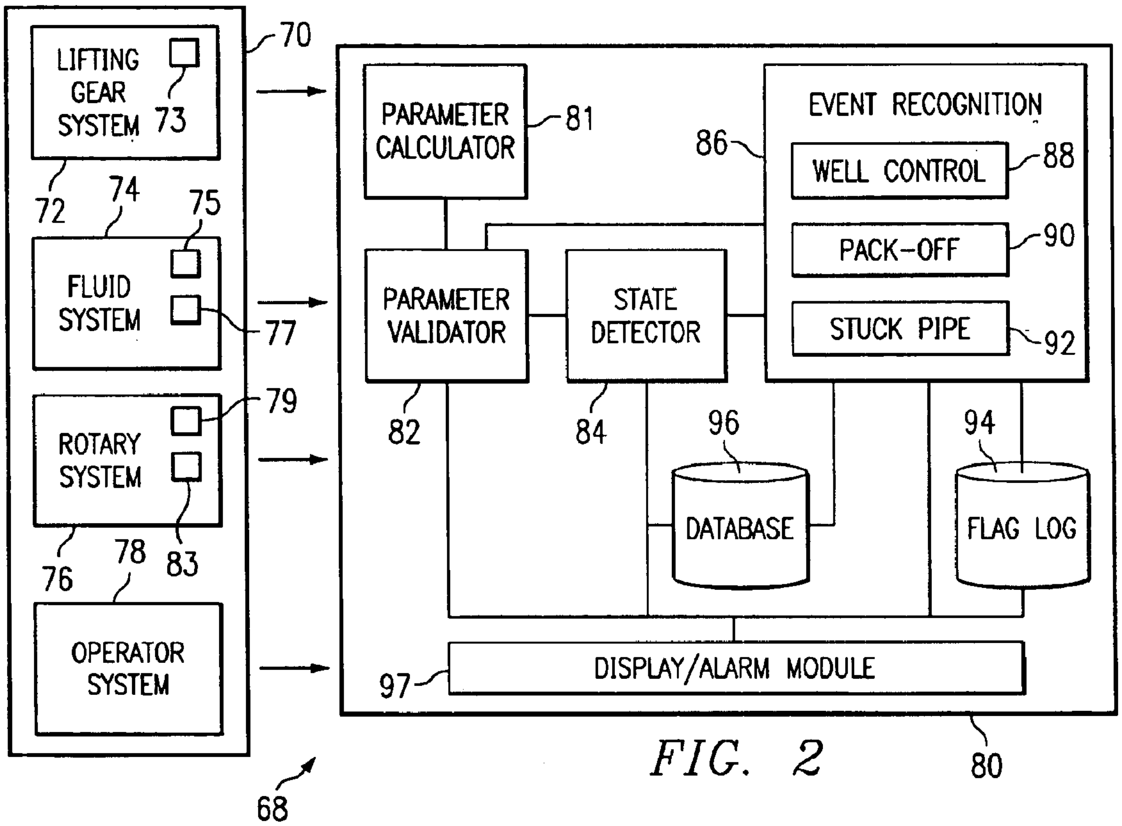

LIFTING GEAR SYSTEM
73
72
74
75
FLUID SYSTEM
77
ROTARY SYSTEM
79
76
78
83
OPERATOR SYSTEM
70
68
PARAMETER CALCULATOR
81
PARAMETER VALIDATOR
82
STATE DETECTOR
84
86
EVENT RECOGNITION
WELL CONTROL
88
PACK-OFF
90
STUCK PIPE
92
96
DATABASE
94
FLAG LOG
97
DISPLAY/ALARM MODULE
80

FIG. 2

FIG. 3

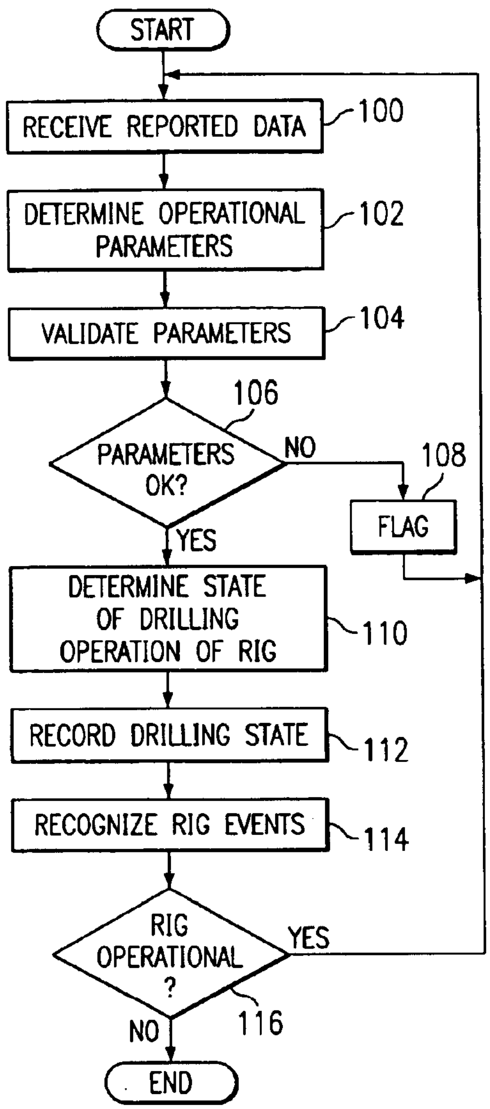

START
RECEIVE REPORTED DATA
100
DETERMINE OPERATIONAL PARAMETERS
102
VALIDATE PARAMETERS
104
106
PARAMETERS OK?
NO
108
FLAG
YES
DETERMINE STATE OF DRILLING OPERATION OF RIG
110
RECORD DRILLING STATE
112
RECOGNIZE RIG EVENTS
114
RIG OPERATIONAL ?
YES
116
NO
END

FIG. 4

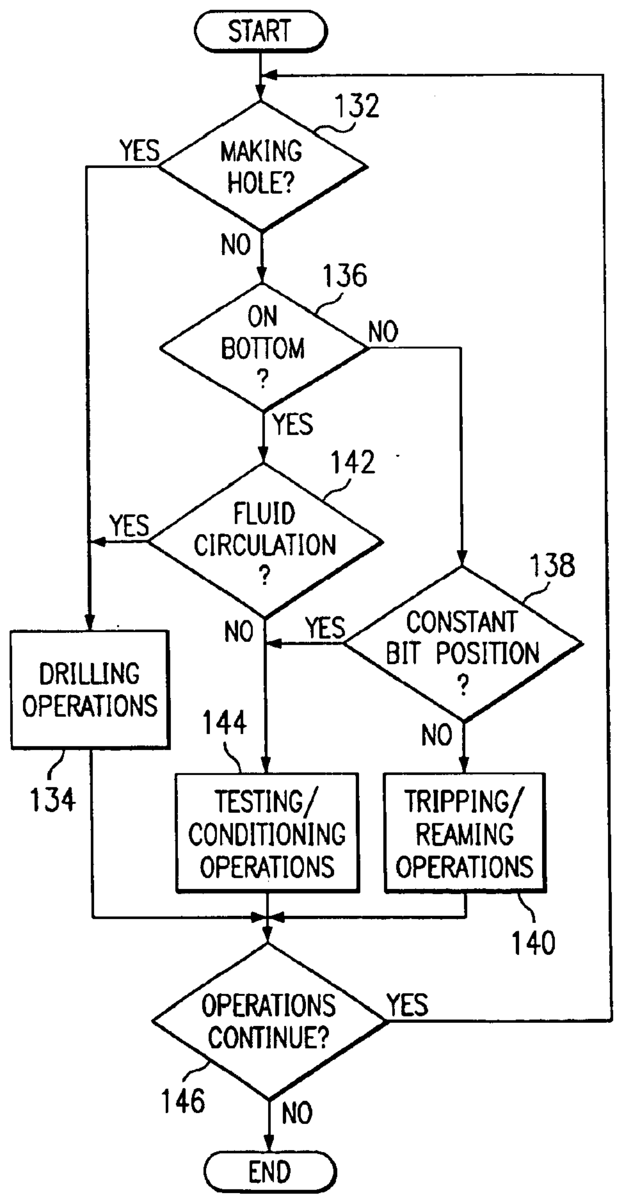

START
132
MAKING HOLE?
YES
NO
136
ON BOTTOM ?
NO
YES
142
FLUID CIRCULATION ?
YES
138
CONSTANT BIT POSITION ?
DRILLING OPERATIONS
NO
YES
134
144
NO
TESTING/ CONDITIONING OPERATIONS
TRIPPING/ REAMING OPERATIONS
140
OPERATIONS CONTINUE?
YES
146
NO
END

FIG. 5A

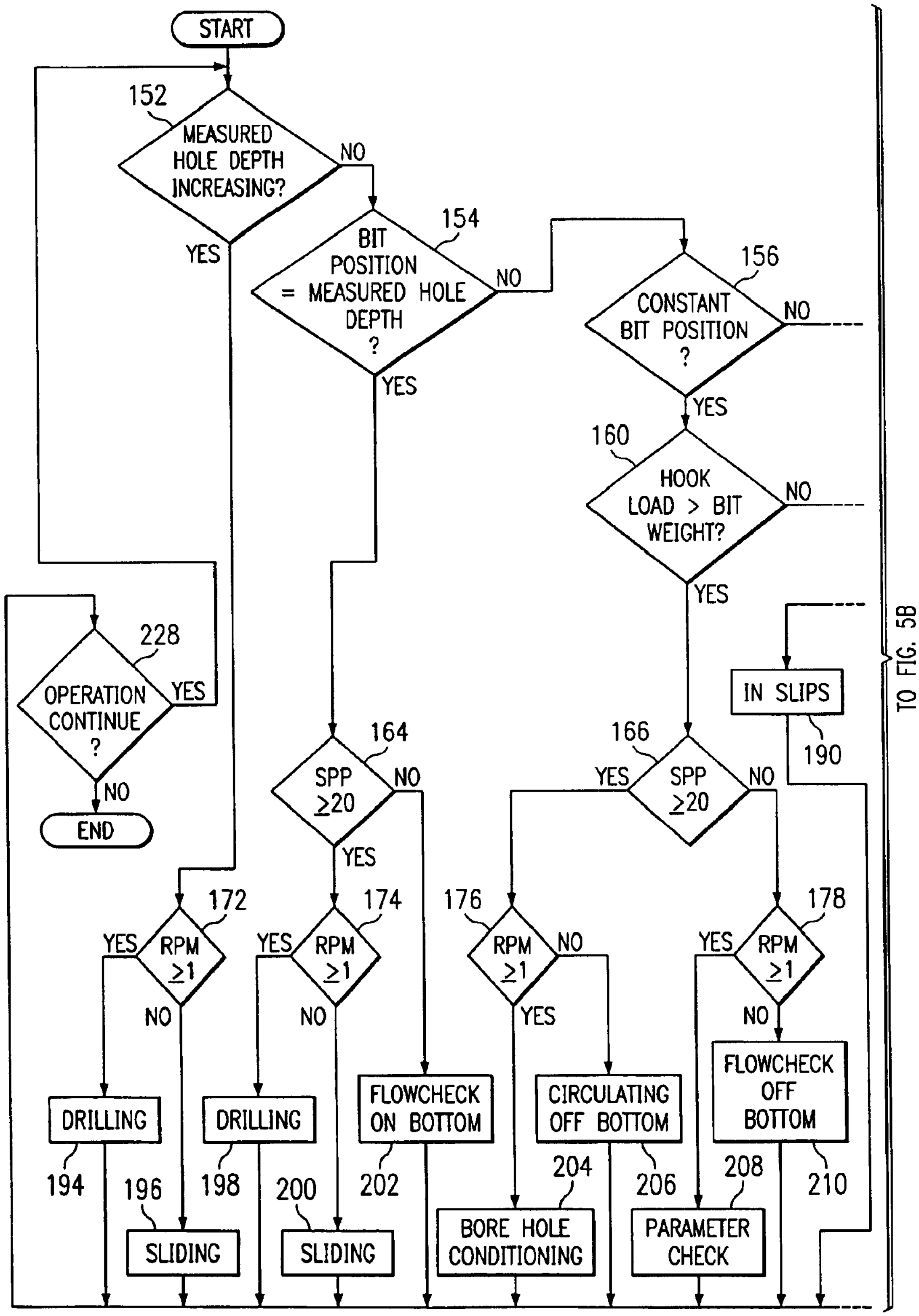
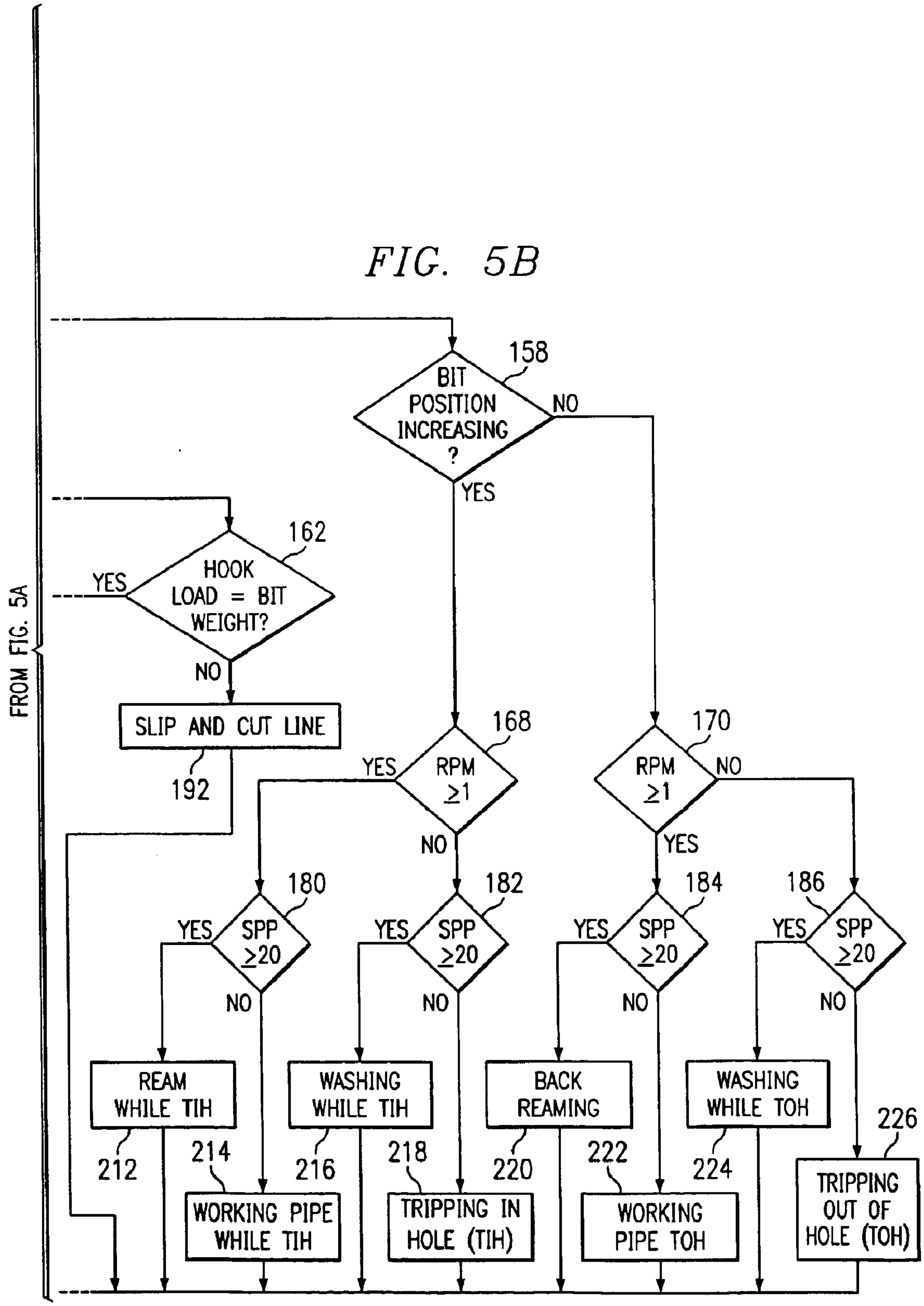

START
152
MEASURED HOLE DEPTH INCREASING?
NO
YES
154
BIT POSITION = MEASURED HOLE DEPTH ?
NO
YES
156
CONSTANT BIT POSITION ?
NO
YES
160
HOOK LOAD > BIT WEIGHT?
NO
YES
228
OPERATION CONTINUE ?
YES
NO
END
IN SLIPS
190
TO FIG. 5B
164
SPP ≥20
NO
YES
166
SPP ≥20
YES
NO
172
RPM ≥1
YES
NO
174
RPM ≥1
YES
NO
176
RPM ≥1
NO
YES
178
RPM ≥1
YES
NO
DRILLING
194
DRILLING
198
FLOWCHECK ON BOTTOM
202
CIRCULATING OFF BOTTOM
206
FLOWCHECK OFF BOTTOM
210
196
SLIDING
200
SLIDING
204
BORE HOLE CONDITIONING
208
PARAMETER CHECK

FIG. 5B


158
BIT POSITION INCREASING ?
NO
YES
162
HOOK LOAD = BIT WEIGHT?
YES
NO
FROM FIG. 5A
SLIP AND CUT LINE
192
168
RPM ≥1
YES
NO
170
RPM ≥1
NO
YES
180
SPP ≥20
182
SPP ≥20
184
SPP ≥20
186
SPP ≥20
YES
NO
REAM WHILE TIH
212
WASHING WHILE TIH
216
BACK REAMING
220
WASHING WHILE TOH
224
214
WORKING PIPE WHILE TIH
218
TRIPPING IN HOLE (TIH)
222
WORKING PIPE TOH
226
TRIPPING OUT OF HOLE (TOH)

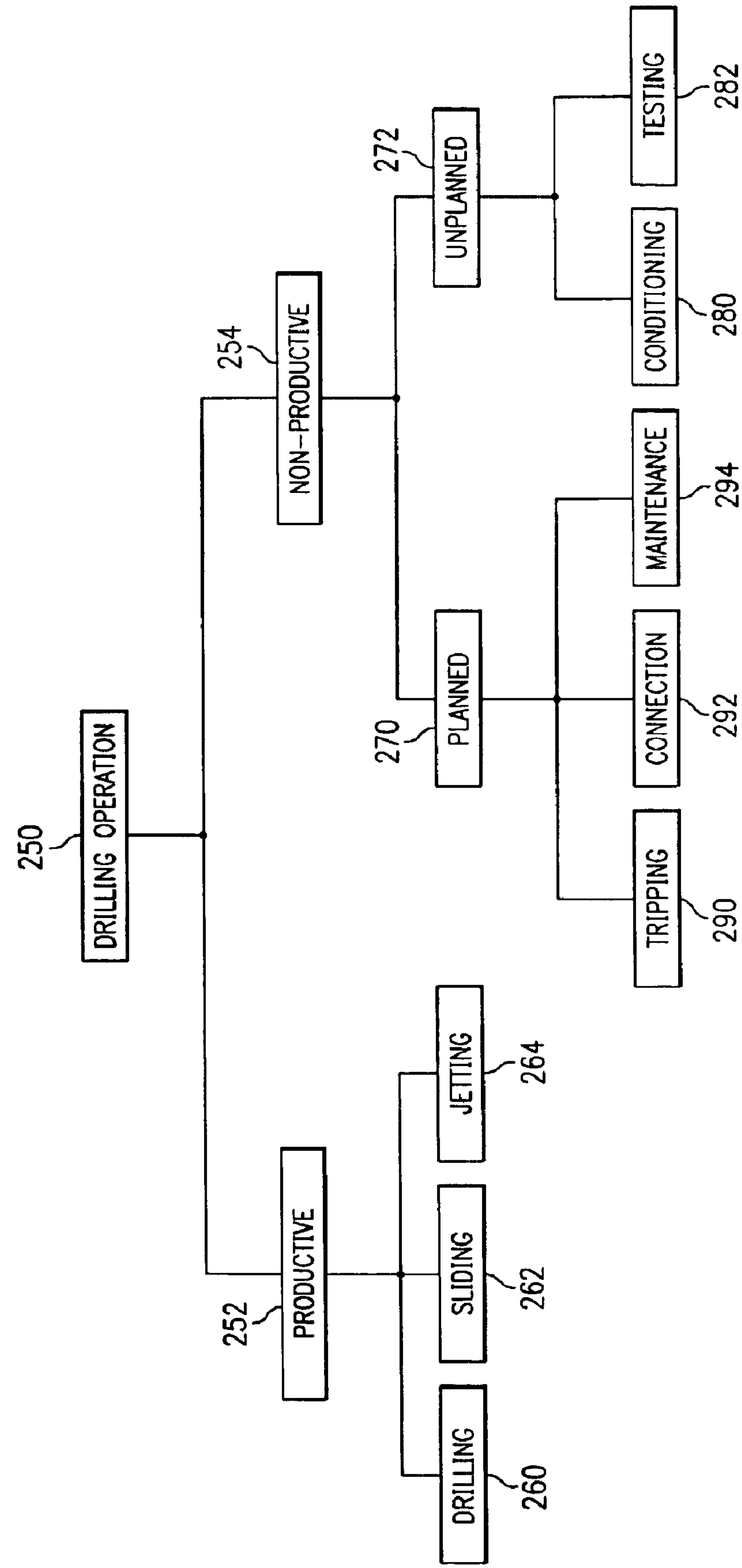

250
DRILLING OPERATION
252
PRODUCTIVE
254
NON-PRODUCTIVE
260
DRILLING
262
SLIDING
264
JETTING
270
PLANNED
272
UNPLANNED
290
TRIPPING
292
CONNECTION
294
MAINTENANCE
280
CONDITIONING
282
TESTING

FIG. 6

AUTOMATED METHOD AND SYSTEM FOR DETERMINING THE STATE OF WELL OPERATIONS AND PERFORMING PROCESS EVALUATION

TECHNICAL FIELD

This invention relates generally to the field of drilling management systems, and more particularly to an automated method and system for determining the state of drilling and other well operations and performing process evaluation.

BACKGROUND

Drilling rigs are typically rotary-typed rigs that use a sharp bit to drill through the earth. At the surface, a rotary drilling rig often includes a complex system of cables, engines, support mechanisms, tanks, lubricating devices, and pulleys to control the position and rotation of the bit below the surface.

Underneath the surface, the bit is attached to a long drill pipe which carries drilling fluid to the bit. The drilling fluid lubricates and cools the bit, as well as removes cuttings and debris from the well bore. In addition, the drilling fluid provides a hydrostatic head of pressure that prevents the collapse of the well bore until it can be cased and that prevents formation fluids from entering the well bore, which can lead to gas kicks and other dangerous situations.

Automated management of drilling rig operations is problematic because parameters may change quickly and because down hole behavior of drilling elements and down hole conditions may not be directly observable. As a result, many management systems fail to accurately recognize the presence and/or absence of important drilling events, which may lead to false alarms and unnecessary down time.

SUMMARY

The present invention provides an automated method and system for determining the state of drilling and other well operations. Process evaluation may be performed for the operation based on the state and dynamic data for the operation. In a particular embodiment, the present invention determines the state of drilling operations based on bit behavior to allow accurate and timely event recognition during drilling operations. In other embodiments, the present invention determines the state of work over, completion, testing, abandonment, intervention and/or other well operations of the drilling industry based on sensed, verified, inferred and/or determined mechanical and hydraulic data.

In accordance with one embodiment of the present invention, an automated method for monitoring the state of a well operation comprises storing a plurality of states for the well operation. Mechanical and hydraulic data is sensed and reported for the well operation. Based on the mechanical and hydraulic data, one of the states is automatically selected as the state of the well operation. The state may be used for process evaluation, decision making and control functionality.

Technical advantages of some embodiments of the present invention include providing an automated method and system for determining the state of a well operation based on mechanical and/or hydraulic data sensed, inferred, and/or determined for the operation. The data may be sensed and processed down hole and/or at the surface and in connection with operations for the well. As a result, well reporting, management or event recognition may be automatically provided in connection with the well operation.

Another technical advantage of some embodiments of the present invention includes providing an automated method and system for effectively determining the state of a drilling operation. In particular, the drilling, tripping, reaming, testing, and/or conditioning state of a rig may be determined in real time and used for reporting, event recognition and/or rig management.

Still another technical advantage of some embodiments of the present invention includes providing an improved drilling or other rig used for well operations. In particular, sensed and/or reported data is utilized to enhance accuracy. In addition, the automated and real time state determination may allow for earlier, more effective and more efficient recognition of potentially hazardous events such as kickouts, stuck pipe, and pack off, thus resulting in the more effective taking of corrective operations and a reduction in the frequency and severity of undesirable events.

It will be understood that the various embodiments of the present invention may include some, all, or none of the enumerated technical advantages. In addition, other technical advantages of the present invention may be readily apparent from the following figures, description and claims.

BRIEF DESCRIPTION

For a more complete understanding of the present invention and its advantages, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** is a schematic diagram of a drilling rig in accordance with one embodiment of the present invention;

FIG. **2** is a block diagram of a monitoring system for a drilling operation in accordance with one embodiment of the present invention;

FIG. **3** is a flow diagram illustrating a method for monitoring a drilling operation in accordance with one embodiment of the present invention;

FIG. **4** is a flow diagram illustrating a method for determining the state of a drilling operation in accordance with one embodiment of the present invention;

FIGS. **5**A–B are flow diagrams illustrating a method for determining the state of a drilling operation in accordance with another embodiment of the present invention; and

FIG. **6** is a block diagram illustrating states for a drilling operation in accordance with another embodiment of the present invention.

DETAILED DESCRIPTION

The present invention provides an automated method and system for determining the state of well operations. In one embodiment, as described with particularity below, the present invention may be used to automatically determine the state of drilling operations. In other embodiments, as also described below, the present invention may be used to determine the state of mud fluid circulation and other drilling systems or subsystems, as well as the state of other suitable well operations. For example, the state engine of the present invention may be used to determine the status of work over, completion, re-entry, tubing runs and exchanges as well as other suitable well operations. The well operations may be rig-performed operations with a rig on site or other activity performed over the life of an oil, gas or other suitable well. In each of these embodiments, the well operations are typically complex processes in which state determination involves a number of parameters from a number of systems and/or locations. For example, a drilling

operation may include parameters measured and/or representing surface as well as down hole conditions and equipment. The state determination may be based on mechanical and hydraulic data, may be determined to a high resolution and/or may be determined based on input from a number of systems. Thus, the state engine may provide comprehensive state determination in order to support control evaluation and/or decision making functionality for a well operation. Control evaluation and/or decision making functionally is supported, in one embodiment, where operational conditions and status are provided and determined to allow accurate and automatic control of all, a substantial portion or at least a majority of aspects of well operations with little or no direct input from human operators.

FIG. **1** illustrates a drilling rig **10** in accordance with one embodiment of the present invention. In this embodiment, the rig **10** is a conventional rotary land rig. However, the present invention is applicable to other suitable drilling technologies and/or units, including top drive, power swivel, down hole motor, coiled tubing units, and the like, and to non-land rigs, such as jack up rigs, semisubmersables, drill ships, mobile offshore drilling units (MODUs), and the like that are operable to bore through the earth to resource-bearing or other geologic formations.

The rig **10** includes a mast **12** that is supported above a rig floor **14**. A lifting gear includes a crown block **16** mounted to the mast **12** and a travelling block **18**. The crown block **16** and the travelling block **18** are interconnected by a cable **20** that is driven by draw works **22** to control the upward and downward movement of the travelling block **18**.

The travelling block **18** carries a hook **24** from which is suspended a swivel **26**. The swivel **26** supports a kelley **28**, which in turn supports a drill string, designated generally by the numeral **30** in the well bore **32**. A blow out preventor (BOP) **35** is positioned at the top of the well bore **32**. The string may be held by slips **58** during connections and rig-idle situations or at other appropriate times.

The drill string **30** includes a plurality of interconnected sections of drill pipe or coiled tubing **34** and a bottom hole assembly (BHA) **36**. The BHA **36** includes a rotary drilling bit **40** and a down hole, or mud, motor **42**. The BHA **36** may also include stabilizers, drill collars, measurement well drilling (MWD) instruments, and the like.

Mud pumps **44** draw drilling fluid, or mud, **46** from mud tanks **48** through suction line **50**. The drilling fluid **46** is delivered to the drill string **30** through a mud hose **52** connecting the mud pumps **44** to the swivel **26**. From the swivel **26**, the drilling fluid **46** travels through the drill string **30** to the BHA **36**, where it turns the down hole motor **42** and exits the bit **40** to scour the formation and lift the resultant cuttings through the annulus to the surface. At the surface, the mud tanks **48** receive the drilling fluid from the well bore **32** through a flow line **54**. The mud tanks **48** and/or flow line **54** include a shaker or other device to remove the cuttings.

The mud tanks **48** and mud pumps **44** may include trip tanks and pumps for maintaining drilling fluid levels in the well bore **32** during tripping out of hole operations and for receiving displaced drilling fluid from the well bore **32** during tripping-in-hole operations. In a particular embodiment, the trip tank is connected between the well bore **32** and the shakers. A valve is operable to divert fluid away from the shakers and into the trip tank, which is equipped with a level sensor. Fluid from the trip tank can then be directly pumped back to the well bore via a dedicated centrifugal pump instead of through the standpipe.

Drilling is accomplished by applying weight to the bit **40** and rotating the drill string **30**, which in turn rotates the bit **40**. The drill string **30** is rotated within bore hole **32** by the action of a rotary table **56** rotatably supported on the rig floor **14**. Alternatively or in addition, the down hole motor may rotate the bit **40** independently of the drill string **30** and the rotary table **56**. As previously described, the cuttings produced as bit **40** drills into the earth are carried out of bore hole **32** by the drilling fluid **46** supplied by pumps **44**.

FIG. **2** illustrates a well monitoring system **68** in accordance with one embodiment of the present invention. In this embodiment, the monitoring system is a drilling monitoring system **68** for the rig **10**. The monitoring system **68** comprises a sensing system **70** and a monitoring module **80** for drilling operations of the rig **10**. Well monitoring systems for other well operations may comprise a sensing system with sensors similar, analogous or different to those of sensing system **70** for use in connection with a monitoring module, which may be similar, analogous or different than module **80**. As described in more detail below, drilling operations may comprise drilling, tripping, testing, reaming, conditioning, and other and/or different operations, or states, of the drilling system. A state may be any suitable operation or activity or set of operations or activities of which all, some or most are based on a plurality of sensed parameters.

The sensing system **70** includes a plurality of sensors that monitor, sense, and/or report data, or parameters, on the rig **10**, and/or in the bore hole **32**. The reported data may comprise the sensed data or may be derived, calculated or inferred from sensed data.

In the illustrated embodiment, the sensing system **70** comprises a lifting gear system **72** that reports data sensed by and/or for the lifting gear; a fluid system **74** that reports data sensed by and/or for the drilling fluid tanks, pumps, and lines; rotary system **76** that reports data sensed by and/or for the rotary table or other rotary device; and an operator system **78** that reports data input by a driller/operator. As previously described, the sensed data may be refined, manipulated or otherwise processed before being reported to the monitoring module **80**. It will be understood that sensors may be otherwise classified and/or grouped in the sensor system **70** and that data may be received from other additional or different systems, subsystems, and items of equipment. The systems that perform a well operation, which in some contexts may be referred to as subsystems, may each comprise related processes that together perform a distinguishable, independent, independently controllable and/or separable function of the well operation and that may interact with other systems in performing their function of the operation.

The lifting gear system **72** includes a hook weight sensor **73**, which may comprise digital strain gauges or other sensors that report a digital weight value once a second, or at another suitable sensor sampling rate. The hook weight sensor may be mounted to the static line (not shown) of the cable **20**.

The fluid system **74** includes a stand pipe pressure sensor **75** which reports a digital value at a sampling rate of the pressure in the stand pipe. The drilling fluid system may also include a mud pump sensor **77** that measures mud pump speed in strokes per minute, from which the flow rate of drilling fluids into the drill string can be calculated. Additional and/or alternative sensors may be included in the drilling fluid system **74** including, for example, sensors for measuring the volume of fluid in mud tank **46** and the rate of flow into and out of mud tank **46**. Also, sensors may be included for measuring mud gas, flow line temperature, and mud density.

The rotary system **76** includes a rotary table revolutions per minute (RPM) sensor **79** which reports a digital value at a sampling rate. The RPM sensor may also report the direction of rotation. A rotary torque sensor **83** may also be included which measures the amount of torque applied to drill string **34** during rotation. The torque may be indicated by measuring the amount of current drawn by the motor that draws rotary table **46**. The rotary torque sensor may alternatively sense the tension in the rotary table drive chain.

The operator system **78** comprises a user interface or other input system that receives input from a human operator/driller who may monitor and report observations made during the course of drilling. For example, bit position (BPOS) may be reported based upon the length of the drill string **30** that has gone down hole, which in turn is based upon the number of drill string segments the driller has added to the string during the course of drilling. The driller/operator may keep a tally book of the number of segments added, and/or may input this information in a Supervisory Control and Data Acquisition (SCADA) reporting system.

Other parameters may be reported or calculated from reported values. For example, other suitable hydraulic and/or mechanical data may be reported. Hydraulic data is data related to the flow, volume, movement, rheology, and other aspects of drilling or other fluid performing work or otherwise used in operations. The fluids may be liquid, gaseous or otherwise. Mechanical data is data related to support or physical action upon or of the drill string, bit or any other suitable device associated with the drilling or other operation. Mechanical and hydraulic data may originate with any suitable device operable to accept, report, determine, estimate a value, status, position, movement, or other parameter associated with a well operation. As previously described, mechanical and hydraulic data may originate from machinery sensor data such as motor states and RPMs and for electric data such as electric power consumption of top drive, mud transfer pumps or other satellite equipment. For example, mechanical and/or hydraulic data may originate from dedicated engine sensors, centrifugal on/off sensors, valve position switches, fingerboard open/close indicators, SCR readings, video recognition and any other suitable sensor operable to indicate and/or report information about a device or operation of a system. In addition, sensors for measuring well bore trajectory, and/or petrophysical properties of the geologic formations, as well down hole operating parameters, may be sensed and reported. Down hole sensors may communicate data by wireline, mud pulses, acoustic wave, and the like. Thus, the data may be received from a large number of sources and types of instruments, instrument packages and manufacturers and may be in many different formats. The data may be used as initially reported or may be reformatted and/or converted. In a particular embodiment, data may be received from two, three, five, ten, twenty, fifty, a hundred or more sensors and from two, three, five, ten or more systems. That data and/or information determined from the data may be a value or other indication of the rate, level, rate of change, acceleration, position, change in position, chemical makeup, or other measurable information of any variable of a well operation.

The monitoring module **80** receives and processes data from the sensing system **70** or from other suitable sources and monitors the drilling system and conditions based on the received data. As previously described, the data may be from any suitable source, or combinations of sources and may be received in any suitable format. In one embodiment, the monitoring system **80** comprises a parameter calculator **81**,

a parameter validator **82**, a drilling state determination detector **84**, an event recognition module **86**, a database **96**, a flag log **94**, and a display/alarm module **97**. It will be understood that the monitoring system **80** may include other or different programs, modules, functions, database tables and entries, data, routines, data storage, and other suitable elements, and that the various components may be otherwise integrated or distributed between physically disparate components. In a particular embodiment, the monitoring module **80** and its various components and modules may comprise logic encoded in media. The logic may comprise software stored on a computer-readable medium for use in connection with a general purpose processor, or programmed hardware such as application-specific integrated circuits (ASIC), field programmable gate arrays (FPGA), digital signal processors (DSP) and the like.

The parameter calculator **81** derives/infers or otherwise calculates state indicators for drilling operations based on reported data for use by the remainder of monitoring system **80**. Alternatively, the calculations could be conducted by processes or units within the sensing systems themselves, by an intermediary system, the drilling state detector **84**, or by the individual module of the monitoring system **80**. A state indicator is a value or other parameter based on sensed data and is indicative of the state of drilling operations. In one embodiment, the state indicators comprise measured depth (MD), hook load (HKLD), bit position (BPOS), stand pipe pressure (SPP), and rotary table revolutions per minute (RPM).

The state indicators, either directly reported or calculated via calculator **81** and other parameters, may be received by the parameter validator **82**. The parameter validator **82** recognizes and eliminates corrupted data and flags malfunctioning sensor devices. In one embodiment, the parameter validation compares each parameter to a status and/or dynamic allowable range for the parameter. The parameter is flagged as invalid if outside the acceptable range. As used herein, each means every one of at least a subset of the identified items. Reports of corrupted data or malfunctioning sensor devices can be sent to and stored in flag log **94** for analysis, debugging, and record keeping.

The validator **82** may also smooth or statistically filter incoming data. Validated and filtered parameters may be directly utilized for event recognition, or may be utilized to determine the state drilling operations of the rig **10** via the drilling state determination detector **84**.

The drilling state determination detector **84** uses combinations of state indicators to determine the current state of drilling operations. The state may be determined continuously at a suitable update rate and in real time. A drilling state is an overall conclusion regarding the status of the well operation at a given point in time based on the operation of and/or parameters associated with one or more key drilling elements of the rig. Such elements may include the bit, string, and drilling fluid.

In one embodiment, the drilling state determinator modules **84** stores a plurality of possible and/or predefined states for drilling operations for the rig **10**. The states may be stored by storing a listing of the states, storing logic differentiating the states, storing logic operable to determine disparate states, predefining disparate states or by otherwise suitably maintaining, providing or otherwise storing information from which disparate states of an operation can be determined. In this embodiment, the state of drilling operations may be selected from the defined set of states based on the state indicators. For example, if the bit is substantially off

bottom, there is no substantial rotation of the string, and drilling fluid is substantially circulating, then based on this set of state indicators, drilling state detector **84** determines the state of drilling operations to be and/or described as circulating off bottom. On the other hand, if the drill bit is moving into the hole and the string is rotating, but there is no circulation of drilling fluid, the state of drilling operations can be determined to be and/or described as working pipe. Examples and explanations of these and other drilling states and their determination by the drilling state determination module **84** may be found in reference to FIGS. **4** and **5**. The states may be stored locally and/or remotely, may be titled or untitled, may be represented by any suitable type of signal and may be determined mathematically, by comparisons, by logic trees, by lookups, by expert systems such as an inferencing engine and in any other suitable manner. The states may be sections or parts of a continuous spectrum. Thus, for example, the state may be determined by selection of a predefined state based on matching criteria and/or one or more comparisons. The state may be determined repetitively, continuously, substantially continuously or otherwise. A process is substantially continuous when it is continuous for a majority of processes for a well operation and/or cycles on a periodic basis on the order of magnitude of a second, or less.

The event recognition module **86** receives drilling parameters and/or drilling state conclusions and recognizes or flags events, or conditions. Such conditions may be alert conditions such as hazardous, troublesome, problematic or noteworthy conditions that affect the safety, efficiency, timing, cost or other aspect of a well operation. For drilling operations, drilling events comprise potentially significant, hazardous, or dangerous happenings or other situations encountered while drilling that may be important to flag or bring to the attention of a drilling supervisor. Events may include stuck pipe, pack off, or well control events such as kicks.

The event recognition module **86** may comprise submodules operable to recognize different kinds of events. For example, well control events such as kick-outs may be recognized via operation of well control sub-module **88**. A well control event is any suitable event associated with a well that can be controlled by application or adjustment of a well fluid, flow, volume, or device such as circulation of fluid during drilling operations. Pack-off events, such as, for example, when drill cuttings clog the annulus, may be recognized via operation of pack-off sub-module **90**, and stuck pipe events may be recognized via operation of stuck pipe sub-module **92**. Other events may be useful to recognize and flag, and the event recognition module **86** may be configured with other modules with which this is accomplished. Control evaluation and/or decisions may be performed continuously, repetitively and/or substantially continuously as previously described. In another embodiment, the state and event recognition may be performed in response to one or more predefined events or flags that arise during the well operation.

Drilling parameters, drilling states, event recognitions, and alert flags may be displayed to the user on display/alarm module **97**, stored in database **96**, and/or made accessible to other modules within monitoring system **80** or to other systems or users as appropriate. Database **96** may be configured to record trends in data over time. From these data trends it may be possible, for example, to infer and flag long-term effects such as bore-hole degradation caused by repeated tripping within the bore hole.

In operation, the monitoring system **80** may allow for an increase in quality control with respect to sensing devices and the monitoring of the timing and efficiency of drilling operations. Events such as kickouts may be accurately detected and flagged while drilling earlier than is possible via human observation of rig operations, thus resulting in the more effective taking of corrective operations and a reduction in the frequency and severity of undesirable events. In addition, the provisioning of state information may allow false alarms to be minimized, more accurate event recognition and residual down time. Another potential benefit may be an increased ability to automate daily and end-of-well reporting procedures.

The states may be determined, control evaluation provided, and/or events recognized without manual or other input from an operator or without direct operator input. Operator input may be direct when the input forms a state indicator used directly by the state engine. In addition, the state, evaluation and recognition processes may be performed without substantial operator input. For example, processes may run independently of operator input but may utilize operator overrides of erroneous readings or other analogous inputs during instrument or other failure conditions. It will be understood that a process may run independently of operator input during operation and/or normal operation and still be manually, directly, or indirectly started, initiated, interrupted or stopped. With or without operator input, the state recognition processes are substantially based on instrument sensed parameters that are monitored in real-time and dynamically changing.

FIG. **3** illustrates a method for monitoring a rig in accordance with one embodiment of the present invention. In this embodiment, the state of drilling operation is determined and drilling events are recognized based on operational data and the drilling state. It will be understood that events may be otherwise determined or suitably recognized and that drilling may be otherwise suitably monitored without departing from the scope of the present invention.

Referring to FIG. **3**, the method begins at step **100** with the receipt of reported data by the monitoring system **80**, while the rig is operating. The data may be from the lifting gear system **72**, the drilling fluid system **74**, the rotary system **76**, the driller/operator system **78** and/or from other sensors or systems of the drilling rig **10**. Some of the data may constitute parameters usable in their present form or format. In other cases, state indicators or other parameters are calculated from the reported data at step **102**.

At step **104**, the parameters are validated and filtered. Validation may be accomplished by comparing the parameters to pre-determined or dynamically determined limits, and the parameters used if they are within those limits. Filtering may occur via the use of filtering algorithms such as Butterworth, Chebyshev type I, Chebyshev type II, Elliptic, Equiripple, least squares, Bartlett, Blackman, Boxcar, Chebyshev, Hamming, Hann, Kaiser, FFT, Savitzky Golay, Detrend, Cumsum, or other suitable data filter algorithms.

Next, at decisional step **106**, for any data failing validation, the No branch of decisional step **106** leads to step **108**. At step **108**, the invalid data is flagged and recorded in the flag log. After flagging, step **108** leads back to step **100**. Determinations based on inputs for which invalid data was received may be omitted during the corresponding cycle. Alternatively, a previous value of the input may be used, or a value based on a trend of the input may be used.

Returning to decisional step **106**, for those parameters that are validated, the Yes branch leads to step **110**. At step **110**, validated and filtered operational parameters may be utilized

to determine the state of drilling operations of the rig **10**. The drilling state determined at step **110** and data trends may be recorded in the database **96** at step **112**. At step **114**, drilling state information and operational parameters are utilized to recognize drilling events, as described above.

Proceeding to decisional step **116**, if the rig **10** remains in operation, the Yes branch returns to step **100** and continues the method as long as the rig is operational. If the rig **10** is deactivated or otherwise not operational, the No branch of decisional step **116** leads to the end of the process. The process may be operated once or more times per second, or at other suitable intervals. In this way, continuous and real time monitoring of drilling operations may be provided.

FIG. **4** illustrates a method for determining the state of drilling operations for the drilling rig **10** in accordance with one embodiment of the present invention. In this embodiment, the drilling states of the drilling rig **10** may comprise and/or be divided into three general categories: (1) drilling; (2) testing/conditioning operations; and (3) tripping/reaming. The drilling state or states include those where the rig **10** is operating so as to drill through the earth or to attempt to do so by the rotation of the drilling bit **40**. Drilling may include jetting, or washing, in part, in whole or otherwise as well as any operation operable to bore through the earth and/or remove earth from a bore hole. Jetting may be using mainly hydraulic force for rock destruction. Thus, drilling may include hammer/percussion and laser drilling. It will be understood that unsuccessful drilling may be a separate state or states. The testing/conditioning state or states are operations (other than tripping or reaming operations) used to check or test certain aspects of equipment performance, change out bits, line, or other equipment, change to a different drilling mud, condition a particular part of the bore annulus, or similar operations. The tripping/reaming state or states are operations that include the travel of the bit up or down the already-drilled bore hole.

In the embodiment shown in FIG. **4**, four types of state indicators are considered by the drilling state detector **84** in determining the state of drilling operations: (1) whether the rig is "making hole" (substantially increasing the total length of the bore hole), (2) whether the bit is substantially on bottom, (3) whether the bit position is substantially constant, and (4) whether there is substantial circulation of the drilling fluid.

Referring to FIG. **4**, the method begins at step **132** in which the parameter calculator **81**, drilling state detector **84**, or other logic determines whether the drilling rig **10** is making hole. This may be done by determining whether the measured depth of the hole is increasing. If hole is being made, the Yes branch of decisional step **137** leads to step **134**. At step **134**, the drilling state detector **84** determines that drilling operations are occurring.

Returning to decisional step **132**, if hole is not being made, the No branch leads to decisional step **136**. At step **136**, the detector **84** determines whether the drill bit is at bottom of the bore hole **32**. In one embodiment, the drill bit is at the bottom of the bore hole if the measured depth is equal to bit position.

If the bit is on the bottom, the Yes branch of decisional step **136** leads to decisional step **142**, where detector **84** determines whether drilling fluid is circulating through the drill string **30**, out of the drill bit **40**, and through the rest of the fluid system. Parameters used for making this determination may include stand pipe pressure (SPP), strokes per minute (SPM) of the mud pump, total strokes, inflow rate, outflow rate, triptank level, mud pit level, or other suitable hydraulic parameters. A lower limit of these parameters may be chosen for making the determination; for example, experience may show that a SPP of greater than twenty psi is indicative that the drilling fluid is substantially circulating within the hydraulic system.

If circulation is occurring at decisional step **142**, detector **84** concludes that drilling operations are occurring, suggesting that relatively strong rock at the bottom of the bore is resulting in a situation where drilling operations are occurring, but little or no hole is being made. Accordingly, the Yes branch of decisional step **142** leads to step **134**.

Returning to decisional step **142**, if there is not circulation, the method concludes at step **144** that the drilling state of the rig **10** is undergoing testing/conditioning operations.

Returning to decisional step **136**, if the bit is not on the bottom, the No branch leads to decisional step **138** wherein it is determined whether bit position within the hole is constant; that is, whether the position of the bit relative to the terminus of the bore is remaining constant. If the bit position is constant, the Yes branch leads to step **144** where, as previously described, it is determined that the drilling state of the rig **10** is undergoing testing/conditioning operations. Returning to decisional step **138**, if the bit position is not constant, the No branch leads to step **140**. At step **140**, the drilling state is determined to be tripping and/or reaming operations.

After the drilling state of the rig is determined based on steps **134**, **144**, or **140**, the process leads to decisional step **146**, where it is determined whether operations continue. If operations continue, the Yes branch returns to decisional step **132**, where the drilling state of the rig continues to be determined as long as the operations continue. If operations are at an end, the No branch of decisional step **146** leads to the end of the process where the drilling state is determined repetitively and/or substantially continuously and in real and/or near real time.

It will be understood that other, additional or a subset of these states may be used for drilling operations. For example, in another embodiment, the states may comprise a drilling/reaming state indicating formation or other material being removed from a bore hole, a tripping state indicating tripping in or out of the hole, a testing/condition state indicating those operations and a connection/maintenance state indicating a process interruption. In still another embodiment, as described in connection with FIG. **5**, the state detector **84** may have a high resolution or granularity with five, ten, fifteen or more states. As previously described, the resolution, and thus number and type of states is preferably selected to support control evaluation, decision making and/or provide process evaluation. Process evaluation may be evaluation of parameters, information and other data in the control and decision making context. For example, process evaluation may provide indications and warnings of hazardous events. Data and/or state reporting for archiving may also be provided.

FIGS. **5**A–B illustrate a method for determining the drilling state of the drilling rig **10** in accordance with another embodiment of the present invention. In this embodiment, granularity of the drilling states is increased to support enhanced monitoring, reporting, logging and event recognition capabilities. In particular, each of the drilling operations state, the testing/conditioning operations state, and the tripping/reaming operations state are subdivided into a plurality of states.

In one embodiment, drilling state is subdivided into rotary drilling state (stated simply as "drilling" on FIG. **5**) and

sliding state. Rotary drilling occurs when the rotation of the bit **40** is caused at least in part by the rotation of the drill string **30** which, in turn, is caused by the rotation of the rotary table **56** or other device. In sliding, bit rotation is caused by the operation of a down hole bit motor or turbine rather than by the rotation of the drill string **30**. In one embodiment, rotary drilling may include sliding and washing and sliding may include washing.

Likewise, testing/conditioning operations are subdivided into an in slips state, a slip and cut line state, a flow check on bottom state, a bore hole conditioning state, a circulating off bottom state, a parameter check state, and a flow check off bottom state.

In slips occurs when the string **30** is set in slips and the string weight is off the hook **24**. This state typically occurs during connections and rig-idle situations. Slip and cut line occurs when the string is set in slips and the travelling block assembly is removed so as to, for example, replace worn drilling line. Flow check on bottom occurs when drilling fluid **46** is not circulating and the bit position is on bottom and static. Bore hole conditioning occurs when drilling fluid **46** is circulating, bit position is static and off bottom, and string **30** is rotating. Bore hole conditioning typically occurs when the well bore **32** is being conditioned by cleaning out cuttings or other resistance in the drill pipe/bore-hole-wall annulus. Circulating off bottom occurs when the bit **40** is off bottom, there is no rotation of the string **30**, and drilling fluid **46** is circulating. Circulating off bottom typically occurs when mud is changed, fluid pills are placed, or if the well is cleaned out. Parameter check occurs when the string **30** is off bottom and rotating, and drilling fluid **46** is not circulating. Hook load may be measured during parameter check to be used for torque and drag simulations. Flow check off bottom occurs when drilling fluid **46** is not circulating and bit position is static and off bottom. Flow check off bottom typically occurs during a check to determine if the well is flowing (gaining formation fluid) or losing (drilling mud is flowing into formation).

Tripping/reaming operations can be subdivided into a tripping in hole (TIH) state, a tripping out of hole (TOH) state, a reaming while TIH state, a reaming while TOH state, a working pipe state, a washing while TIH state, and a washing while TOH state.

Tripping in hole (TIH) occurs when re-entering a hole after pulling back to the surface. Alone, the term describes TIH with no rotation and no circulation. Tripping out of hole (TOH) occurs when pulling bit off bottom for a short or round trip to surface. Alone, the term describes TOH with no rotation and no circulation. Reaming occurs when the drill bit is moving into the hole, drilling fluid is circulating, and string is rotating. Reaming while TIH is typically used in order to clean out cuttings or other obstructions. Reaming while TOH ("back reaming") is used with dedicated back-reaming tools to clean out sedimented cuttings or obstructions. Working pipe (while TIH or TOH) occurs when the drill bit is moving into the hole, string is rotating, but there is no circulation of drilling fluid. Working pipe is typically used to manage stabilizers or to move the bit past restrictions or ease the movement of the drill string in horizontal well-sections. Washing (while TIH or TOH) occurs when the drill bit is moving into the hole, string is not rotating, and drilling fluid is circulating. Washing while TIH typically is utilized to wash out cuttings before setting the bit on bottom for drilling.

Referring to FIG. **5**, the method begins at step **152** where it is determined, similar to the embodiment described in FIG. **4**, whether the rig is making hole. Specifically, step **152** may make this determination by determining whether or not the measured depth is increasing. If measured depth is increasing, the method then determines at step **172** whether the RPM of the rotary table are greater than or equal to one. If the RPM of the rotary table is greater than or equal to one, it is determined at step **194** that rotary table drilling is occurring. If the RPM is less than one at decisional step **172**, then it is determined that the rig is sliding.

Returning to decisional step **152**, if the measured depth is not increasing, it is next determined at decisional step **154** if the bit position is equal to the measured depth. If the bit position is equal to the measured depth, then at step **164** it is determined whether there is circulation. In the illustrated embodiment, the parameter of stand pipe pressure is used to determine the circulation parameter such that if the stand pipe is greater than or equal to twenty pounds per square inch (psi), then circulation of drilling fluid is determined to be occurring.

At decisional step **174**, it is determined whether or not the RPM of the rotary table is greater than or equal to one. Again, if the RPM is greater than or equal to one, the rig is determined to be (rotary table) drilling and if the RPM is not greater than or equal to one, the rig is determined to be sliding in accordance with steps **198** and **200**, respectively. Returning to step **164**, if the stand pipe pressure is less than twenty psi, then the drilling behavior is determined at step **212** to be flow check on bottom.

Returning to step **154**, if the bit position does not equal measured depth, then at step **156** it is determined whether or not the bit position is constant. If the bit position is constant, at step **160** it is next determined whether the hook load is greater than bit weight. If the hook load is greater than bit weight, at step **166** it is determined whether the stand pipe pressure is greater than or equal to twenty psi. If the stand pipe pressure is greater than or equal to twenty psi, then at step **176** it is determined whether the RPM is greater than or equal to one. If the RPM is greater than or equal to one, the drilling behavior is determined to be bottom hole conditioning at step **204**. If the RPM is not greater than or equal to one, then, at step **206**, the status is determined to be circulating off bottom.

Returning to step **166**, if the stand pipe is less than twenty psi, then, at step **178**, it is determined whether the RPM is greater than or equal to one. If the RPM is greater than or equal one, at step **208**, the drilling behavior is determined to be parameter check. If the RPM is not greater than or equal to one, the drilling behavior is determined at step **210** to be flow check off bottom.

Returning to decisional step **160**, if the hook load is not greater than the bit weight, it is next determined at step **162** whether the hook load equals the bit weight. The hook load may equal bit weight if it is the same or substantially the same as the bit weight or within specified deviation of the bit weight. If the hook load equals the bit weight, the drilling behavior is determined to be in slips at step **190**. If the hook load does not equal the bit weight, at step **192**, the drilling behavior is determined to be in slips with the line cut above the slips.

Returning to decisional step **156**, if the bit position is not constant, it is next determined at decisional step **158** whether the bit position is increasing. If the bit position is increasing, then at step **168** it is determined whether the RPM is greater than or equal to one. If the RPM is greater than or equal to one, at step **180** it is determined whether the stand pipe pressure is greater than or equal to twenty psi. If the stand

pipe pressure is greater than or equal to twenty psi, the drilling behavior is determined to be reaming while tripping in hole at step **212**. If the stand pipe pressure is less than twenty psi, then at step **214** the status is determined to be working pipe while tripping in hole.

If the RPM is less than one at decisional step **168**, it is then determined at step **182** whether the stand pipe pressure is greater than or equal to twenty psi. If the stand pipe pressure is greater than or equal to twenty psi, the status is determined to be washing while tripping in hole at step **216**. If the stand pipe pressure is less than twenty psi, the status is determined to be tripping in hole at step **218**.

Returning to decisional step **158**, if the bit position is not increasing, it is next determined at step **170** whether the RPM is greater than or equal to one. If the RPM is greater than or equal to one, at step **184**, it is determined whether the stand pipe pressure is greater than or equal to twenty psi. If the stand pipe pressure is greater than or equal to twenty psi, at step **220** the status is determined to be back reaming. If the stand pipe pressure is less than twenty psi, at step **222** the status is determined to be working pipe while tripping out of hole.

Returning to decisional step **170**, if the RPM is not greater than or equal to one, at step **186**, if the stand pipe pressure is greater than or equal to twenty psi, then the drilling behavior is at step **224** determined to be washing while tripping out of hole. If the stand pipe pressure is less than twenty psi at step **186**, the drilling behavior is at step **226** determined to be tripping out of hole. After the drilling behavior has been determined, it is next determined at step **228** whether or not operations continue. If operations continue, then parameters continue to be entered into the system and the determination method continues. If operations are not continuing, then the method has reached its end.

FIG. **6** illustrates states of a well operation in accordance with another embodiment of the present invention. In this embodiment, the state of a drilling or other well operation may include hierarchal states with parent and child states. For example, a drilling or other well operation **250** may have a productive state **252** and a non-productive state **254**. For drilling operations, the productive state **252** may include processes in which hole is being made, the bit is advancing or is operated so as to advance. In a particular embodiment, the productive state may include and/or have drilling **260**, sliding **262** and/or jetting **264** or combination states as described in connection with FIG. **5**. In some drilling embodiments, reaming may be included in the productive state. In other well operations, the productive state may be the state that is the focus or ultimate purpose of the well operation.

The non-productive state **254** may include support or other processes that are planned, unplanned, needed, necessary or helpful to the production state or states. The non-productive state may include and/or have a planned state **270** and an unplanned state **272**. For drilling operations, the unplanned state **272** may include and/or have a conditioning state **280** and a testing state **282**. The planned state may include and/or have a tripping state **290** as well as a connection state **292** and a maintenance state **294**. Maintenance may include rig and hole maintenance. It will be understood that some operations, such as tripping may have aspects in both planned and unplanned states. The states may be determined based on state indicators and data as previously described with the parent and/or child states being determined and used for process evaluation. The parent states may be determined based on the previously discussed

state indicators of the included, or underlying, child states, a subset of the indicators or otherwise. Thus, for example, the drilling operation **250** may have the productive state **252** if measured hole depth is increasing or if bit position is equal to measured hole depth and stand pipe pressure is greater than or equal to 20 psi. Maintenance may, for example, include hole maintenance such as reaming and/or rig maintenance such as slip and cut line.

Although the present invention has been described with reference to drilling rig **10** and the corresponding states of drilling operations, the invention may be used to determine one or more states associated with other suitable petroleum and geosystem operations for a well. Such well operations may include work-over procedures, well completions, natural-gas operations, well testing, cementing, well abandonment, well stimulation, acidizing, squeeze jobs, wire line applications and water/fluid treatment.

For example, mud fluid circulation systems generally include a series of stages that may be identified by using mechanical and hydraulic data as feedback from the associated system. Mud fluid circulation systems are generally used to maintain hydrostatic pressure for well control, carry drill cuttings to the surface, and cool and/or lubricate the drill bit during drilling. The mud or water used to make up the drilling fluid may require treatment to remove dissolved calcium and/or magnesium. Soda ash may be added to form a precipitate of calcium carbonate. Caustic soda (NaOH) may also be added to form magnesium hydroxide. Accordingly, fluid characteristics (such as pressure and fluid-flow rate) and chemical-based parameters may be suitably monitored in accordance with the teachings of the present invention in order to determine one or more of the identified states or other states of the operations.

In addition, production procedures and activities (such as fracs, acidizing, and other well-stimulating techniques) represent another example of petroleum operations within the scope of the present invention. Production operations may encompass any operations involved in bringing well fluids (or natural gas) to the surface and may further include preparing the fluids for transport to a suitable refinery or a next processing destination, and well treatment procedures used generally to optimize production. The first step in production is to start the well fluids flowing to the surface (generally referred to as "well completion"). Well servicing and workover consists of performing routine maintenance operations (such replacing worn or malfunctioning equipment) and performing more extensive repairs, respectively. Well servicing and workover are an intermittent step and generally a prerequisite in order to maintain the flow of oil or gas. Fluid may be then separated into its components of oil, gas, and water and then stored and treated (for purification), suitably measured, and properly tested where appropriate before being transported to a refinery. Well workovers may additionally involve recompletion in a different pay zone by deepening the well or by plugging back. In accordance with the teachings of the present invention, each of these procedures may be monitored such that feedback is provided in order to determine one or more of the identified states or other states of the corresponding operation.

Additionally, well or waste treatments represent yet another example of petroleum operations that include various stages that may be identified with use of the present invention. Well or waste treatments generally involve the use of elements such as: paraffin, slop oil, oil and produced water-contaminated soils. In well or waste treatments, purification and refinement stages could provide suitable feed-

back in offering mechanical data for selecting a corresponding state. Such states may include, for example, collecting, pre-treatment, treatment, settling, neutralization and out pumping.

Thus the monitoring system of the present invention may be used in connection with any suitable system, architecture, operation, process or activity associated with petroleum or geosystem operations of a well capable of providing an element of feedback data such that a stage associated with the operation may be detected, diagnosed, or identified is within the scope of the present invention. In these operations, the drilling rig **10** may not be on location. In these embodiments, such as in connection with frac jobs and stimulation, sensor data may be retrieved via wireline and/or mud pulses from down hole equipment and/or directly from surface equipment and systems.

In non-drilling applications, any suitable reference point may be tracked. For example, for pumping operations, pure volumetric data may be tracked and used to determine the state of operations. In all of these embodiments, the monitoring system may include a sensing system for sensing, refining, manipulating and/or processing data and reporting the data to a monitoring module. The sensed data may be validated and parameters calculated as previously described in connection with monitoring module **80**. The resulting state indicators may be fed to a state determination module to determine the current state of the operation. The state is the overall conclusion regarding the status at a given point and time based on key measurable elements of the operation. For example, for frac operations, the states may include high and low pressure states, fluid and slurry pumping states, proppant states, and backwash/cleansing states. For acid jobs, the states may include flow and pressure states, pumping states, pH states, and time-based states. Well completion operations may include testing, pumping, cementing and perforating states. For each of these and other well operations, the sensing system may include fluid systems, operator systems, pumping systems, down hole systems, surface systems, chemical analysis systems, and other systems operable to measure and provide data on the well operation.

As previously described, the state determinator module may store a plurality of possible and/or predefined states for the operation. In this embodiment, the state of operations may be selected from the defined set of states based on the state indicators. Events for the operation may be recognized and flagged as previously described.

Although the present invention has been described with several embodiments, various changes and modifications may be suggested to one skilled in the art. It is intended that the present invention encompass such changes and modifications as fall within the scope of the appended claims.

What is claimed is:

1. An automated method for determining the state of a well operation, comprising:

storing a plurality of states for a well operation;

receiving mechanical and hydraulic data reported for the well operation from a plurality of systems; and

determining that at least some of the data is valid by comparing the at least some of the data to at least one limit, the at least one limit indicative of a threshold at which the at least some of the data do not accurately represent the mechanical or hydraulic condition purportedly represented by the at least some of the data; and

when the at least some of the data are valid, based on the mechanical and hydraulic data, automatically selecting one of the states as the state of the well operation.

2. The method of claim **1**, wherein the well operation comprises a drilling operation.

3. The method of claim **2**, wherein at least one of the plurality of states comprises a drilling state.

4. The method of claim **3**, wherein the drilling state comprises rotary drilling.

5. The method of claim **3**, wherein the drilling state comprises sliding.

6. The method of claim **2**, wherein the plurality of states comprises a testing state.

7. The method of claim **6**, wherein the testing state comprises a flow check on bottom.

8. The method of claim **6**, wherein the testing state comprises a flow check off bottom.

9. The method of claim **6**, wherein the testing state comprises a parameter check.

10. The method of claim **2**, wherein at least one of the plurality of states comprises a conditioning state.

11. The method of claim **10**, wherein the conditioning state comprises bottom hole conditioning.

12. The method of claim **10**, wherein the conditioning state comprises circulating off bottom.

13. The method of claim **2**, wherein at least one of the plurality of states comprises a tripping state.

14. The method of claim **13**, wherein the tripping state comprises tripping in hole.

15. The method of claim **13**, wherein the tripping state comprises reaming while tripping in hole.

16. The method of claim **13**, wherein the tripping state comprises working pipe while tripping in hole.

17. The method of claim **13**, wherein the tripping state comprises washing while tripping in hole.

18. The method of claim **13**, wherein the tripping state comprises back reaming while tripping out of hole.

19. The method of claim **13**, wherein the tripping state comprises working pipe while tripping out of hole.

20. The method of claim **13**, wherein the tripping state comprises washing while tripping out of hole.

21. The method of claim **2**, wherein the plurality of states comprises at least a drilling state, a testing state, and a tripping state.

22. The method of claim **2**, further comprising:

determining, based on the mechanical data, whether the hole is being made; and

wherein automatically selecting one of the states comprises selecting the state of the drilling operation based on whether the rig is making hole.

23. The method of claim **2**, further comprising:

determining, based on the mechanical data, whether a drilling bit is on bottom; and

wherein automatically selecting one of the states as the state of the well operation comprises selecting the state of the drilling operation based on whether the drilling bit is on bottom.

24. The method of claim **2**, further comprising:

determining, based on the hydraulic data, whether a drilling fluid is circulating; and

wherein automatically selecting one of the states as the state of the well operation comprises selecting the state of the drilling operation based on whether the drilling fluid is circulating.

25. The method of claim **2**, further comprising:

determining, based on the mechanical data, whether a bit position is constant; and

wherein automatically selecting one of the states as the state of the well operation comprises selecting the state

of the drilling operation based on whether the bit position is constant.

26. The method of claim **2**, further comprising indicating the state of the drilling operation.

27. The method of claim **2**, further comprising recognizing a drilling event based on the state of the drilling operation and data reported for the drilling operation.

28. The method of claim **2**, wherein at least one of the plurality of states comprises an in slips state.

29. The method claim **2**, wherein at least one of the plurality of states comprises a slip and cut line state.

30. The method of claim **1**, further comprising using the state of the well operation to evaluate parameters and provide control for the well operation.

31. An automated system for determining the state of a well operation comprising:

means for storing a plurality of states for a well operation;

means for determining that at least some received mechanical and hydraulic data is valid by comparing the at least some of the data to at least one limit, the at least one limit indicative of a threshold at which the at least some of the data does not accurately represent the mechanical or hydraulic condition purportedly represented by the at least some of the data; and

means for automatically selecting one of the states based on mechanical and hydraulic data as the state of the well operation when the at least some of the mechanical and hydraulic data are valid.

32. The system of claim **31**, wherein the well operation comprises a drilling operation.

33. The system of claim **32**, wherein at least one of the plurality of the states comprises a drilling state.

34. The system of claim **33**, wherein the drilling state comprises rotary drilling.

35. The system of claim **33**, wherein the drilling state comprises sliding.

36. The system of claim **32**, wherein the plurality of states comprises a testing state.

37. The system of claim **36**, wherein the testing state comprises a flow check on bottom.

38. The system of claim **36**, wherein the testing state comprises a flow check off bottom.

39. The system of claim **36**, wherein the testing state comprises a parameter check.

40. The system of claim **32**, wherein at least one of the plurality of states comprises a conditioning state.

41. The system of claim **40**, wherein the conditioning state comprises bottom hole conditioning.

42. The system of claim **40**, wherein the conditioning state comprises circulating off bottom.

43. The system of claim **32**, wherein at least one of the plurality of states comprises a tripping state.

44. The system of claim **43**, wherein the tripping state comprises tripping in hole.

45. The system of claim **43**, wherein the tripping state comprises reaming while tripping in hole.

46. The system of claim **45**, wherein the tripping state comprises working pipe while tripping in hole.

47. The system of claim **45**, wherein the tripping state comprises washing while tripping in hole.

48. The system of claim **45**, wherein the tripping state comprises back reaming while tripping out of hole.

49. The system of claim **45**, wherein the tripping state comprises working pipe while tripping out of hole.

50. The system of claim **45**, wherein the tripping state comprises washing while tripping out of hole.

51. The system of claim **32**, wherein the plurality of states comprises at least a drilling state, a testing state, and a tripping state.

52. The system of claim **32**, further comprising:

means for determining whether the hole is being made based on the mechanical data; and

means for determining the state of the drilling operation based on whether the rig is making hole.

53. The system of claim **32**, further comprising:

means for determining whether a drilling bit is on bottom based on the mechanical data; and

means for determining the state of the drilling operation based on whether the drilling bit is on bottom.

54. The system of claim **32**, further comprising:

means for determining whether a drilling fluid is circulating based on the hydraulic data; and

means for determining the state of the drilling operation based on whether the drilling fluid is circulating.

55. The system of claim **32**, further comprising:

means for determining whether a bit position is constant based on the mechanical data; and

means for determining the state of the drilling operation based on whether the bit position is constant.

56. The system of claim **32**, further comprising means for indicating the state of the drilling operation.

57. The system of claim **32**, further comprising means for recognizing a drilling event based on the state of the drilling operation and data reported for the drilling operation.

58. The system of claim **32**, wherein at least one of the plurality of states comprises an in slips state.

59. The system claim **32**, wherein at least one of the plurality of states comprises a slip and cut line state.

60. The system of claim **31**, further comprising means for using the state of the well operation to evaluate parameters and provide control for the operation.

61. An automated system for determining the state of a well operation, comprising:

logic encoded in media; and

the logic operable to receive mechanical and hydraulic data reported for the well operation from a plurality of systems, determine that at least some of the received data is valid by comparing the at least some of the received data to at least one limit, the at least one limit indicative of a threshold at which the at least some of the received data do not accurately represent the condition purportedly represented by the at least some of the received data, and to automatically select one of the states as the state of the well operation based on the mechanical and hydraulic data when the at least some of the received data are valid.

62. The system of claim **61**, wherein the well operation comprises a drilling operation.

63. The system of claim **62**, wherein at least one of the plurality of states comprises a drilling state.

64. The system of claim **63**, wherein the drilling state comprises rotary drilling.

65. The system of claim **63**, wherein the drilling state comprises sliding.

66. The system of claim **62**, wherein the at least one of the plurality of states comprises a testing state.

67. The system of claim **66**, wherein the testing state comprises a flow check on bottom.

68. The system of claim **66**, wherein the testing state comprises a flow check off bottom.

69. The system of claim **66**, wherein the testing state comprises a parameter check.

70. The system of claim **62**, wherein at least one of the plurality of states comprises a conditioning state.

71. The system of claim **70**, wherein the conditioning state comprises bottom hole conditioning.

72. The system of claim **70**, wherein the conditioning state comprises circulating off bottom.

73. The system of claim **70**, wherein at least one of the plurality of states comprises a tripping state.

74. The system of claim **73**, wherein the tripping state comprises tripping in hole.

75. The system of claim **73**, wherein the tripping state comprises reaming while tripping in hole.

76. The system of claim **73**, wherein the tripping state comprises working pipe while tripping in hole.

77. The system of claim **73**, wherein the tripping state comprises washing while tripping in hole.

78. The system of claim **73**, wherein the tripping state comprises back reaming while tripping out of hole.

79. The system of claim **73**, wherein the tripping state comprises working pipe while tripping out of hole.

80. The system of claim **73**, wherein the tripping state comprises washing while tripping out of hole.

81. The system of claim **62**, wherein the plurality of states comprises at least a drilling state, a testing state, and a tripping state.

82. The system of claim **62**, the logic further operable to:

determine whether the hole is being made based on the mechanical data; and

determine the state of the drilling operation based on whether the rig is making hole.

83. The system of claim **62**, the logic further operable to:

determine whether a drilling bit is on bottom based on the mechanical data; and

determine the state of the drilling operation based on whether the drilling bit is on bottom.

84. The system of claim **62**, the logic further operable to:

determine whether a drilling fluid is circulating based on the hydraulic data; and

determine the state of the drilling operation based on whether the drilling fluid is circulating.

85. The system of claim **62**, the logic further operable to:

determine whether a bit position is constant based on the mechanical data; and

determine the state of the drilling operation based on whether the bit position is constant.

86. The system of claim **62**, the logic further operable to indicate the state of the drilling operation.

87. The system of claim **62**, the logic further operable to recognize a drilling event based on the state of the drilling operation and data reported for the drilling operation.

88. The system of claim **62**, wherein at least one of the plurality of states comprises an in slips state.

89. The system claim **62**, wherein at least one of the plurality of states comprises a slip and cut line state.

90. The system of claim **61**, the logic further operable to use the state of the well operation to evaluate parameters and provide control for the operation.

91. An automated method for determining a state of a drilling operation comprising:

receiving mechanical and hydraulic data reported for a drilling operation;

based on the mechanical and hydraulic data, determining a state of the drilling operation; wherein the state of the drilling operation is determined to be:

drilling if:

a hole is being made; or

a hole is not being made, a drill bit associated with the drilling operation is on bottom and drilling fluid associated with the drill bit is circulating;

testing/conditioning if:

a hole is not being made, the drill bit is on bottom and the drilling fluid is not circulating; or

a hole is not being made, the drill bit is off bottom and the drill bit has a constant position; and

tripping/reaming if:

a hole is not being made, the drill bit is off bottom and the position of the drill bit is not constant.

92. The method of claim, **91**, wherein the state of the drilling operation is determined to be in slips if a hole is not being made, the drill bit is off bottom, the drill bit has a constant bit position and a hook load associated with the drilling operation is substantially equal to a block weight associated with the drilling operation.

93. The method of claim **91**, wherein the state of the drilling operation is determined to be slip and cut line if a hole is not being made, the drill bit is off bottom, the drill bit has a constant bit position and a hook load associated with the drilling operation is less than a block weight associated with the drilling operation.

94. An automated method for determining the state of a well operation, comprising:

storing a plurality of states comprising at least a productive and a non-productive state for the well operation;

receiving mechanical and hydraulic data reported for the well operation; and

determining that at least some of the data is valid by comparing the data to at least one limit, the at least one limit indicative of a threshold at which the at least some of the data do not accurately represent the mechanical or hydraulic condition purportedly represented by the at least some of the data; and

when the at least some of the data are valid, based on the mechanical and hydraulic data, automatically selecting one of the plurality of states as the state of the well operation.

95. The method of claim **94**, wherein the well operation comprises a drilling operation.

96. The method of claim **95**, wherein the productive state comprises a drilling state.

97. The method of claim **96**, wherein the drilling state comprises rotary drilling.

98. The method of claim **96**, wherein the drilling state comprises sliding.

99. The method of claim **95**, wherein the non-productive state comprises a planned state.

100. The method of claim **99**, wherein the planned state comprises at least one of a connection state, a maintenance state and a tripping state.

101. The method of claim **95**, wherein the non-productive state comprises an unplanned state.

102. The method of claim **101**, wherein the unplanned state comprises at least one of a conditioning state and a testing state.

103. The method of claim **94**, wherein the state is selected without direct input from an operator.

104. The method of claim **94**, wherein the state is selected without input from an operator.

105. An automated system for determining the state of a well operation, comprising:

logic encoded in media; and

the logic operable to receive mechanical and hydraulic data reported for the well operation, determine that at least some of the received data is valid by comparing the data to at least one limit, the at least one limit indicative of a threshold at which at least some of the

data do not accurately represent the condition purportedly represented by the at least some of the received data, and to automatically select one of a productive state and a non-productive state as a state of the well operation based on the mechanical and hydraulic data when the at least some of the received data are valid.

106. The method of claim **105**, wherein the well operation comprises a drilling operation.

107. The method of claim **106**, wherein the productive state comprises a drilling state.

108. The method of claim **107**, wherein the drilling state comprises rotary drilling.

109. The method of claim **107**, wherein the drilling state comprises sliding.

110. The method of claim **106**, wherein the non-productive state comprises a planned state.

111. The method of claim **110**, wherein the planned state comprises at least one of a connection state, a maintenance state and a tripping state.

112. The method of claim **106**, wherein the non-productive state comprises an unplanned state.

113. The method of claim **112**, wherein the unplanned state comprises at least one of a conditioning state and a testing state.

114. The method of claim **105**, wherein the state is selected without direct input from an operator.

115. The method of claim **105**, wherein the state is selected without input from an operator.

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